PROBLEMY EKOROZWOJU/ PROBLEMS OF SUSTAINABLE DEVELOPMENT

SUBMITTED: 4.12.2026, ACCEPTED: 30.12.2026, PUBLISHED ON-LINE: 1.07.2026
2026, 21(2): 199-223, DOI: https://doi.org/10.35784/preko.8839

Green Finance and Human Health Outcomes: The Role of Public Renewable Energy Investment in China, India and Selected Economies

Zielone finanse i ludzkie zdrowie: rola publicznych inwestycji w energię odnawialną w Chinach, Indiach i wybranych innych gospodarkach

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Abstract
Climate-aligned finance is increasingly expected to yield measurable health co-benefits, yet it remains unclear whether public renewable-energy investment translates into better population health in major emerging economies, particularly after COVID-19. This study examines whether climate-focused public renewable-energy finance (green finance) improves human health outcomes, whether environmental quality acts as a transmission channel, and whether the COVID-19 period altered the strength or direction of these relationships. We compile a balanced annual macro-panel for Brazil, China, India, Indonesia, and Mexico over 2000–2023, drawing on harmonised international sources for public renewable-energy finance, health outcomes, emissions, and macro-structural controls. Baseline models are estimated using country fixed effects with Driscoll–Kraay standard errors, complemented by panel-corrected standard errors and Feasible Generalised Least Squares (FGLS) for robustness. A two-equation mediation framework tests environmental quality proxied by CO_2 emissions, with indirect effects evaluated using non-parametric bootstrap inference (1,000 replications). Structural change is assessed via sub-sample estimates for 2000–2019 and 2020–2023, alongside country-specific heterogeneity checks. The results show no robust contemporaneous association between green finance and life expectancy, while the association with under-5 mortality is estimator- and regime-dependent, appearing protective pre-COVID but attenuating during 2020–2023. The CO_2-based mediation pathway is not statistically supported, consistent with a weak first-stage link between green finance and emissions. Overall, the findings refine theory on finance–environment–health linkages and inform practice by indicating that health co-benefits from energy-transition finance are conditional on complementary structural and health-system investments, which is very important from the perspective of sustainable development.

Key words: climate finance, environmental quality, life expectancy, public renewable energy investment, under-5 mortality

Streszczenie
Coraz częściej oczekuje się, że finansowanie nakierowane na klimat przyniesie wymierne korzyści zdrowotne, jednak nadal nie jest jasne, czy publiczne inwestycje w energię odnawialną przekładają się na lepszy stan zdrowia populacji w głównych gospodarkach wschodzących, szczególnie po pandemii COVID-19. W niniejszym artykule analizuje się, czy ukierunkowane na klimat publiczne finansowanie energii odnawialnej (zielone finansowanie) poprawia stan zdrowia ludzi, czy jakość środowiska działa jako kanał transmisji oraz czy okres pandemii COVID-19 zmienił siłę lub kierunek tych zależności. Opracowano zrównoważony roczny makropanel dla Brazylii, Chin,

Indii, Indonezji i Meksyku za lata 2000–2023, opierając się na międzynarodowych źródłach dotyczących publicznego finansowania energii odnawialnej, skutków zdrowotnych, emisji i kontroli makrostrukturalnych. Modele bazowe są szacowane przy użyciu stałych efektów krajowych ze standardowymi błędami Driscolla-Kraaya, uzupełnionymi o błędy standardowe skorygowane o panel oraz FGLS w celu zapewnienia odporności. Dwurównaniowe ramy mediacji testują jakość środowiska związaną z emisjami CO_2, z pośrednimi efektami ocenianymi przy użyciu nieparametrycznego wnioskowania bootstrapowego (1000 powtórzeń). Zmiana strukturalna jest oceniana za pomocą oszacowań podprób dla lat 2000–2019 i 2020–2023, wraz z kontrolami heterogeniczności specyficznymi dla kraju. Wyniki nie wykazują silnego jednoczesnego związku między zielonymi finansami a oczekiwaną długością życia, podczas gdy związek ze śmiertelnością poniżej 5 lat jest zależny od estymatora i systemu, wydając się poozytywny przed COVID-19, ale słabnie w latach pandemii 2020–2023. Ścieżka mediacji oparta na emisjach CO_2 nie jest statystycznie istotna, co jest zgodne ze słabym powiązaniem pierwszego etapu między zielonymi finansami a emisjami. Ogólnie rzecz biorąc, wyniki badań dopracowują teorię dotyczącą powiązań między finansami, środowiskiem i zdrowiem oraz wskazują, że korzyści zdrowotne wynikające z finansowania transformacji energetycznej zależą od uzupełniających się inwestycji strukturalnych i w system opieki zdrowotnej, co jest bardzo istotne z perspektywy zrównoważonego rozwoju.

Słowa kluczowe: finansowanie klimatyczne, jakość środowiska, oczekiwana długość życia, inwestycje publiczne w energię odnawialną, śmiertelność dzieci poniżej 5. roku życia

1. Introduction

Global efforts to address climate change have increasingly shifted from environmental protection alone to the broader welfare implications of climate action, particularly human health. Environmental degradation and pollution exposure remain major determinants of morbidity and premature mortality, with wide-ranging consequences for development trajectories (Landrigan et al., 2024; Sundas et al., 2024; Jain et al., 2024). At the same time, the expansion of climate-aligned financial instruments has positioned green finance as a core mechanism for accelerating low-carbon transitions and supporting sustainable development outcomes (Sharma et al., 2022; Debrah et al., 2023; Ante, 2024; Joshipura et al., 2025). Within this landscape, public renewable-energy finance is especially salient because it directly targets decarbonisation through investments in clean-energy systems that can reduce pollution-related risks over time (Al Mamun et al., 2022; Zhang et al., 2022; Alharbi et al., 2023). Yet, despite the policy relevance of these investments, empirical evidence remains limited on whether and how climate-focused public renewable-energy finance translates into measurable improvements in population health outcomes (Beyene and Kotosz, 2021; Sidney Correa et al., 2024; Zhang et al., 2024).

Green finance is increasingly conceptualised as a financial architecture that mobilises public and private capital towards environmentally sustainable activities, including renewable energy deployment, energy efficiency, and pollution abatement (Sharma et al., 2022; Debrah et al., 2023). Large-scale bibliometric evidence confirms that the field has matured into a multidisciplinary research domain connecting low-carbon transitions, environmental governance, and sustainable development (Ante, 2024; Joshipura et al., 2025). Empirical studies further document that green finance contributes to climate mitigation through clean-energy expansion and pollution-control technologies, with consistent evidence that green financial flows can reduce carbon emissions in multi-country settings (Al Mamun et al., 2022; Zhang et al., 2022). National evidence also suggests that climate-aligned finance and policy packages can lower local pollutant concentrations, including sulphur dioxide, nitrogen dioxide, and particulate matter, particularly in rapidly industrialising contexts (Sun et al., 2022). These pathways connect closely to global development priorities by advancing clean energy access, sustainable urban development, and climate action (Iacobuță et al., 2022; He et al., 2023; Behera et al., 2024).

A central rationale for linking climate-focused finance to welfare is that environmental quality constitutes a key bridge between environmental policy and human health. Environmental exposures influence multiple physiological systems, with systematic evidence showing impacts on respiratory, cardiovascular, metabolic, and neurological outcomes (Sundas et al., 2024). Empirical studies also indicate that policy-driven environmental improvements can translate into measurable health gains, including higher life expectancy and reduced child morbidity and mortality (Beyene and Kotosz, 2021; Lawand et al., 2023; Sidney Correa et al., 2024). These findings motivate an expectation that climate-focused investment in renewable energy can generate health co-benefits by reducing harmful exposure pathways, even when health is not the primary target of the investment (Roy, 2024; Li et al., 2022; Zhou et al., 2025). Importantly, human health outcomes matter beyond pollution-related disease mitigation because they are fundamental to human capital formation, productivity, and long-term economic resilience, and environmental degradation remains a substantial contributor to premature deaths globally (Landrigan et al., 2024; Arun et al., 2023).

Despite these advances, three gaps motivate the present study. First, most empirical work linking green finance to environmental improvement relies heavily on pre-2020 data and implicitly assumes stable institutional and health-system conditions, even though COVID-19 constituted a structural break that reshaped health vulnerabilities, fiscal

priorities, and governance capacity (Al Mamun et al., 2022; Zhang et al., 2022; Shamasunder et al., 2020; Gostin et al., 2020; Büyüm et al., 2020). While post-pandemic research has highlighted how air quality and pollution exposure were associated with COVID-19 infection and mortality patterns, direct evidence connecting green finance to population health in the COVID and post-COVID era remains limited (Pansini and Fornacca, 2020; Maheswari et al., 2020; Weaver et al., 2022). Second, cross-country evidence remains uneven: China is frequently examined due to its policy experimentation and green finance scale, but comparative studies that jointly include China and India alongside other major emerging economies remain relatively scarce (Sun et al., 2022; Tong et al., 2020; Ge and Wu, 2025). Third, even where environmental and health linkages are acknowledged, the transmission mechanism is rarely tested formally; studies often treat emissions reduction or environmental indicators as endpoints rather than modelling environmental quality as an intermediate channel connecting green finance to health outcomes (Alharbi et al., 2023; Iacobuţă et al., 2022). Mediation-oriented evidence remains limited even though environmental performance is empirically linked to life expectancy and mortality outcomes (Beyene and Kotosz, 2021; Lawand et al., 2023), and recent work suggests that climate-focused finance may also matter for health system recovery and resilience in climate- and pandemic-exposed settings (Borghi et al., 2024; Teshome et al., 2023).

Against this background, the broad objective of this study is to examine the impact of climate-focused green finance on human health outcomes in emerging economies, with particular reference to China and India, while accounting for the mediating role of environmental quality and post-COVID health dynamics. Specifically, the study assesses the effect of green finance on human health outcomes, examines whether environmental quality mediates the relationship between green finance and health, and investigates whether the COVID-19 period altered the strength or direction of this relationship. These objectives motivate three research questions: does green finance significantly improve human health outcomes in emerging economies; does environmental quality act as a transmission channel through which green finance affects human health outcomes; and did the COVID-19 pandemic change the nature of the green finance–health nexus.

The study contributes to theory and practice in several ways. Conceptually, it aligns with ecological modernisation arguments that targeted financial mechanisms can support low-carbon transition without undermining development, while recognising that outcomes depend on institutional and structural conditions in emerging economies (Bugden, 2022; Ewing, 2017). It also reflects the health–environment–resilience perspective that environmental quality and system capacity shape population health vulnerability and recovery dynamics during shocks (Shamasunder et al., 2020; Borghi et al., 2024). Empirically, the study provides comparative evidence across Brazil, China, India, Indonesia, and Mexico, linking public renewable-energy finance to both longevity and child survival outcomes and formally evaluating the environmental transmission channel. In policy terms, the analysis informs how climate-aligned public investment can support SDG-linked welfare outcomes by clarifying when clean-energy finance is likely to yield health co-benefits and when complementary investments in education, health systems, and resilience are likely to be binding (Iacobuţă et al., 2022; He et al., 2023; Zhang et al., 2024; Virparia et al., 2025).

2. Literature review

2.1. Conceptual foundations of green finance and human health

Green finance is increasingly conceptualised as a financial architecture that mobilises public and private capital towards environmentally sustainable activities, climate mitigation, and pollution abatement, with growing implications for public welfare and human health. It encompasses climate-focused instruments such as green bonds, green credit schemes, carbon markets, green banking models, and public renewable-energy finance, each operating through distinct but complementary investment channels (Sharma et al., 2022; Debrah et al., 2023). Large-scale bibliometric analyses confirm that green finance has evolved into a multidisciplinary field linking low-carbon transitions, environmental governance, and sustainable development outcomes (Ante, 2024; Joshipura et al., 2025). Within this expanding domain, public renewable-energy finance occupies a central position because of its direct role in decarbonisation, emissions reduction, and long-term environmental transformation.

A substantial body of empirical evidence documents the effectiveness of green finance in improving environmental quality and advancing sustainable development. Cross-country analyses show that green financial flows significantly reduce carbon emissions by accelerating clean-energy deployment, promoting energy efficiency, and supporting pollution-control technologies (Al Mamun et al., 2022; Zhang et al., 2022). National-level studies further demonstrate that targeted green finance policies can reduce local air pollutants, including sulphur dioxide, nitrogen dioxide, and particulate matter, particularly in rapidly industrialising economies such as China (Sun et al., 2022). Global evidence also indicates that green bond markets and climate-aligned public finance substantially expand renewable-energy capacity, especially in climate-vulnerable economies (Alharbi et al., 2023). These pathways align closely with the Sustainable Development Goals, notably SDG 7, SDG 11, and SDG 13, by supporting clean energy access, sustainable urbanisation, and climate action through reduced emissions and enhanced adaptive capacity (Iacobuţă et al., 2022; He et al., 2023; Behera et al., 2024).

Improvements in environmental quality constitute a critical bridge between green finance and human health outcomes. A growing interdisciplinary literature demonstrates that environmental conditions shape population health through multiple exposure pathways, including air and water pollution, toxic emissions, and ecosystem degradation. Systematic evidence shows that environmental factors affect respiratory, cardiovascular, metabolic, and neurological health outcomes, with policy-driven environmental improvements translating into measurable health gains (Sundas et al., 2024; Jain et al., 2024). Empirical studies further confirm that stricter environmental regulations and improved environmental performance are associated with higher life expectancy and lower child morbidity and mortality (Beyene and Kotosz, 2021; Lawand et al., 2023; Sidney Correa et al., 2024). These findings reinforce the argument that environmental interventions function simultaneously as public health interventions.

Human health outcomes matter beyond pollution-related disease mitigation because they are fundamental to human capital formation, productivity, and long-term economic resilience. Environmental degradation has been linked to millions of premature deaths annually, with disproportionate impacts on vulnerable populations and lasting consequences for development trajectories (Landrigan et al., 2024). Empirical evidence indicates that improvements in environmental quality yield sustained gains in life expectancy and labour productivity, underscoring health as a core development outcome rather than a peripheral co-benefit (Beyene et al., 2021; Arun et al., 2023).

Emerging economies such as Brazil, China, India, Indonesia, and Mexico are particularly relevant to this nexus due to rapid urbanisation, high energy demand, and significant emissions profiles. These countries account for a substantial share of global pollution exposure while simultaneously leading investments in renewable energy and clean technologies (Tong et al., 2020; Khosla et al., 2020). Urbanisation dynamics, energy transitions, and structural investments in health and education further shape how green finance translates into environmental and health outcomes within these contexts (Onifade and Alola, 2022; Ge and Wu, 2025; Yu et al., 2022). As such, emerging economies provide a critical empirical setting for understanding how climate-focused finance can generate integrated environmental and human health benefits.

2.2. Theoretical framework

This study is grounded in two complementary theoretical perspectives that jointly explain how climate-focused public finance can influence environmental conditions and human health outcomes in emerging economies. The first is Ecological Modernisation Theory (EMT), which provides the economic and institutional rationale for green finance as a driver of low-carbon transition and environmental improvement. The second is the Health–Environment–Resilience Nexus, which explains how changes in environmental quality and system capacity translate into population health outcomes. Together, these frameworks offer a coherent basis for modelling environmental quality as a mediating channel linking green finance to human health.

2.2.1 Ecological Modernisation Theory (EMT)

Ecological Modernisation Theory posits that economic growth and environmental protection are not inherently contradictory, and that modern societies can achieve a relative decoupling of growth from environmental degradation through technological innovation, institutional reform, and targeted financial mechanisms. Central to EMT is the argument that environmental problems can be addressed within existing economic systems by redirecting investment towards cleaner technologies, energy efficiency, and sustainable production processes rather than through growth suppression.

Within this framework, green finance plays a pivotal role by mobilising capital for renewable energy deployment, low-carbon infrastructure, and pollution-abatement technologies. Public renewable-energy investment, in particular, is viewed as a catalyst for technological upgrading and structural transformation, enabling economies to reduce emissions intensity while sustaining economic activity. Empirical evidence supports this channel. For example, Su and Lee (2025) demonstrate that green finance promotes technological innovation and contributes to emissions reduction through enhanced clean-energy investment

EMT further emphasises the role of financial and regulatory institutions in internalising environmental externalities and fostering eco-efficiency. By lowering the cost of capital for renewable energy and clean technologies, green finance facilitates a transition away from fossil fuel dependence and supports long-term environmental modernisation.

However, EMT has notable limitations in developing- and emerging-economy contexts. Critics argue that the theory often assumes institutional capacity, technological readiness, and regulatory enforcement that may not hold in practice. Bugden (2022) shows that increases in environmental technology patents do not necessarily translate into proportional reductions in ecological footprints, particularly where production scale effects dominate efficiency gains . Similarly, Ewing (2017) contends that EMT can understate structural constraints related to inequality, industrial lock-in, and political economy, thereby overstating the automatic benefits of green technological change

These critiques are particularly relevant for large emerging economies such as China, India, Brazil, Indonesia, and Mexico, where rapid industrialisation, urban expansion, and energy demand may initially offset environmental

gains from green investment. As such, EMT in this study is treated not as a deterministic outcome framework, but as a conditional theory whose effectiveness depends on complementary institutional and social factors.

2.2.2 Health–Environment–Resilience Nexus

The Health–Environment–Resilience Nexus provides the conceptual foundation for linking environmental quality to population health outcomes and for understanding how climate-aligned investment may influence health both directly and indirectly. This framework builds on the well-established premise that environmental conditions shape human health through exposure pathways, ecological change, and social vulnerability.

Foundational contributions by Eisenberg et al. (2007) demonstrate that environmental degradation affects disease burdens through interconnected ecological, biological, and socio-economic mechanisms, influencing exposure to air pollution, water contamination, and climate-related stressors Poor environmental quality, particularly elevated air pollution and emissions, is associated with higher incidence of respiratory disease, cardiovascular illness, and premature mortality, while improvements in environmental conditions reduce morbidity and extend life expectancy.

Recent extensions of this framework explicitly incorporate health system resilience and climate risk. Garchitorena et al. (2017) show that interventions targeting environmental determinants can be more effective and cost-efficient than treatment-focused health responses for environmentally driven diseases Yu et al. (2024) further develop an exposure-ecology perspective, highlighting how environmental quality interacts with institutional capacity and socio-economic conditions to shape population health risks

Within this nexus, green finance influences human health outcomes through interconnected environmental and systemic pathways. Climate-focused public investment in renewable energy contributes to environmental improvement by lowering emissions intensity and reducing ambient pollution levels, thereby diminishing population exposure to harmful pollutants. In addition to these direct environmental effects, green finance may also operate through institutional and system-level channels by strengthening health system capacity and resilience. Improved energy reliability, cleaner production structures, and reduced pollution-related disease burdens can ease pressure on health services and free fiscal resources for preventive and curative healthcare, enhancing resilience to climate-related and pandemic shocks. Together, improvements in environmental quality and health system performance translate into better population health outcomes, reflected in longer life expectancy and lower child mortality rates. This integrated perspective provides a clear theoretical justification for modelling environmental quality as a mediating channel through which green finance affects human health outcomes in the empirical analysis.2.2.3 Integrated Conceptual Implications

Taken together, Ecological Modernisation Theory explains how green finance can improve environmental conditions through technological and structural change, while the Health–Environment–Resilience Nexus explains why such improvements matter for human health. The integration of these frameworks supports the study's mediation hypothesis: that green finance influences health outcomes partly through its impact on environmental quality, while also operating within broader socio-economic and institutional constraints characteristic of emerging economies.

2.3. Environmental impacts of climate-focused investments

Climate-focused investments have demonstrated substantial potential to improve environmental quality, with empirical research consistently linking green financial flows to reductions in emissions, ecological footprints and pollution intensity. Evidence from cross-country and panel studies shows that green finance supports environmental protection by lowering carbon emissions and enhancing ecological performance. Numan et al. (2023) report that increases in green finance reduce ecological footprints by 0.28 per cent, while Gollopeni and Mazllami (2024) find significant improvements in environmental protection across 36 OECD countries over 2010–2021. Global evidence further confirms this association: Baştürk (2024) demonstrates that a one per cent rise in green bond issuance contributes to a measurable decline in carbon emissions across 48 countries. These studies span both advanced and emerging economies and rely on robust empirical techniques, providing strong support for the environmental benefits of green finance.

Climate-focused investments also influence renewable-energy deployment, emissions reduction and pollution abatement, although the magnitude and direction of these effects vary by technology type and investment structure. Kwiliński et al. (2024) show that a one-million-dollar increase in off-grid renewable-energy investment reduces CO_2 emissions by 1.18 kt and N_2O emissions by 1.102 kt, with effects materialising after approximately one year. Other evidence highlights the complexity of renewable-energy investments. Yang et al. (2022) find that increases in renewable-energy investment can generate mixed effects: while technological improvements reduce emissions, multiplier effects may temporarily increase them, and the environmental performance of individual technologies differs markedly. Wind-energy investments consistently achieve emissions reductions, whereas certain solar and bioenergy investments may generate short-run emission increases. Hailemariam et al. (2022) show that research

and development investment in renewable technologies enhances environmental quality by reducing multiple pollutants. Collectively, these studies suggest that targeted, well-designed investments are crucial for effective climate mitigation.

In urban contexts, sustainable infrastructure plays an important role in improving environmental quality by reducing pollutant concentrations and mitigating exposure pathways. Green infrastructure influences air quality through deposition, dispersion, absorption and the management of biogenic emissions (Corada et al., 2021). Clean-transport interventions such as electric vehicle deployment and the redesign of urban transport corridors reduce vehicular emissions and improve urban air quality (Glazener and Khreis, 2019). Sustainable building technologies – including energy-efficient materials and on-site renewable-energy systems, also contribute to reducing carbon emissions (Singla, 2024). However, the environmental effectiveness of urban green infrastructure remains context-dependent; Hewitt et al. (2020) argue that while such interventions are beneficial, they are best understood as complementary strategies that operate alongside primary measures such as direct emission reductions.

Case-study evidence from both developed and developing economies further indicates that climate finance contributes meaningfully to emissions reduction and ecological improvement. Lee et al. (2022) find that climate finance reduces carbon emissions, with mitigation finance exerting particularly strong effects in small island developing states. Miao et al. (2025) show that climate finance significantly reduces ecological footprints across developing countries, while Leal et al. (2023) report that the environmental benefits of mitigation finance are especially pronounced in lower-middle-income economies. These improvements tend to strengthen over time, particularly following major international climate agreements. Overall, the evidence confirms that climate-focused investments serve as an important mechanism for improving environmental quality, accelerating clean-energy transitions and reducing pollution-related environmental risks.

2.4.4. Climate-focused investments and human health outcomes

Climate-focused investments, particularly those directed towards clean energy and environmental improvement, have been increasingly linked to population health outcomes through well-documented empirical pathways. A growing cross-country literature demonstrates that clean energy access improves environmental quality by reducing air pollution and fossil-fuel dependence, with direct consequences for human health. Using data from 190 countries, Roy (2024) finds that expanded access to clean energy is positively associated with higher life expectancy, reflecting reduced exposure to harmful emissions and improved living conditions. At the micro-health level, Li et al. (2022) provide clinical and epidemiological evidence that clean energy use is associated with lower prevalence of hypertension, hyperlipidaemia, respiratory diseases, asthma, and depression, highlighting the role of pollution reduction in mitigating both physical and mental health risks. Complementing this evidence, Zhou et al. (2025) document significant declines in chronic lung diseases and depression following clean energy transitions, with mechanism analyses confirming improvements in ambient air quality as the principal transmission channel. These findings are reinforced in developing-country contexts, where Anser et al. (2020) show that clean energy adoption contributes simultaneously to greenhouse gas mitigation and reductions in respiratory disease incidence, underscoring the dual environmental and health dividends of climate-aligned investments.

Beyond clean energy per se, green finance has emerged as an enabling mechanism through which climate-focused investments can influence broader health indicators, including life expectancy, infant mortality, and under-5 mortality. Although the health effects of green finance are less directly observable than those of energy use, recent empirical studies provide indicative evidence of meaningful linkages. Ray and Ganguly (2024) show that declines in infant mortality are closely associated with gains in life expectancy, suggesting that financial and policy interventions targeting early-life health risks can generate long-term population health benefits. In a China-focused study, Zhang et al. (2024) find that higher levels of environmental *greenness*, supported in part by green investment and environmental regulation, are associated with significantly lower infant and under-5 mortality rates. Luo et al. (2021) further demonstrate that green bond financing is negatively related to mortality rates, indicating that capital market instruments targeting environmental objectives may yield indirect health co-benefits through pollution abatement and improved environmental governance. While these studies stop short of establishing universal causal effects, they collectively point to a plausible pathway through which climate-focused finance shapes health outcomes via environmental quality.

The health impacts of climate-aligned investments are also distributed unevenly across populations, with important demographic and equity implications. Evidence suggests that children, older adults, and low-income urban populations are particularly sensitive to environmental conditions, making mortality indicators such as infant and under-5 mortality especially responsive to environmental improvements (Zhang et al., 2024; Li et al., 2022). Virparia et al. (2025) emphasise that comprehensive green finance strategies can promote more inclusive and sustainable development patterns, potentially narrowing health disparities by improving environmental conditions in pollution-intensive and underserved regions. These distributional considerations are particularly salient in emerging economies, where rapid urbanisation, high pollution exposure, and unequal access to clean energy coexist with

expanding green finance initiatives. Taken together, the empirical literature suggests that climate-focused investments can contribute to improved population health not only through aggregate environmental gains but also by addressing structural and demographic health vulnerabilities in developing and emerging economies.

2.5. COVID-19, Climate risk and population health

The COVID-19 pandemic constituted a profound structural break in global health outcomes, exposing long-standing institutional, social, and environmental vulnerabilities that had been largely obscured during periods of relative stability. Shamasunder et al. (2020) argue that the pandemic revealed the fragility of global health systems and the hollowness of prevailing equity narratives, as unequal access to healthcare, vaccines, and essential services became starkly evident across and within countries. This disruption was not confined to clinical capacity but extended to governance structures, as fragmented and nationalist policy responses undermined coordinated international action (Gostin et al., 2020). Büyüm et al. (2020) document how COVID-19 disproportionately affected marginalised populations, ranging from Black, Indigenous, and People of Colour communities in North America to migrant workers in Asia, reinforcing the view that the pandemic magnified pre-existing structural inequalities. As such, COVID-19 represents a systemic rupture that reshaped health outcomes, policy priorities, and the perceived role of non-medical determinants of health.

A central strand of post-pandemic scholarship highlights the interaction between air quality, climate vulnerability, and pandemic severity. Empirical evidence from China, Italy, and the United States shows that regions characterised by high levels of ambient air pollution experienced higher COVID-19 infection rates and mortality (Pansini and Fornacca, 2020; Maheswari et al., 2020). Poor air quality increases the prevalence of pre-existing respiratory and cardiovascular conditions, weakens immune responses, and may facilitate viral persistence and transmission in the atmosphere, thereby intensifying pandemic impacts (Weaver et al., 2022). Pansini et al. (2020) find that pollutants such as nitrogen dioxide and carbon monoxide are strongly correlated with COVID-19 mortality, suggesting that environmental degradation acts as a risk multiplier during public health crises. These findings underscore that climate vulnerability and environmental exposure are not peripheral factors but integral determinants of pandemic outcomes.

Within this context, climate-focused finance has gained prominence as a potential instrument for strengthening health system resilience and supporting recovery in the post-2020 period. Borghi et al. (2024) show that climate finance mechanisms, including multilateral climate funds and adaptive financing arrangements, can enhance the sustainability of health systems by improving infrastructure resilience, energy reliability, and service continuity in climate-vulnerable regions. Such investments are particularly relevant in low- and middle-income countries, where climate shocks and pandemics interact with constrained fiscal space and weak health systems. However, Teshome et al. (2023) caution that political economy barriers and limited implementation capacity continue to restrict the effectiveness of health-focused climate adaptation initiatives. Evidence from post-2020 studies therefore suggests that while climate-focused finance holds promise for enhancing health system resilience in the face of compound climate and pandemic risks, its success depends on institutional reform, inclusive governance, and sustained commitment to integrating environmental and health objectives.

2.6. Research gaps and contribution of the study

Despite the rapid expansion of scholarship on green finance and environmental sustainability, clear gaps remain in the empirical understanding of how climate-focused financial flows translate into human health outcomes, particularly in the post-COVID context. Most existing studies linking green finance to environmental quality rely on pre-2020 data and implicitly assume stable institutional and health-system conditions (Al Mamun et al., 2022; Zhang et al., 2022; Behera et al., 2024). However, COVID-19 constituted a major structural break that reshaped health vulnerabilities, fiscal priorities, and the functioning of environmental and health systems (Shamasunder et al., 2020; Gostin et al., 2020). While a growing body of work examines the interaction between air quality and pandemic severity (Pansini and Fornacca, 2020; Maheswari et al., 2020; Weaver et al., 2022), there is a notable absence of post-COVID empirical evidence that directly links green finance or public renewable-energy investment to population health indicators such as life expectancy and child mortality. This omission limits the policy relevance of the literature in a period characterised by heightened climate and health risks.

A second gap relates to geographic coverage and comparative scope. Although China features prominently in green finance research due to its large green bond market and environmental policy experimentation (Sun et al., 2022; Zhang et al., 2024), far fewer studies adopt a cross-country framework that jointly examines China and India alongside other major emerging economies. India, Brazil, Indonesia, and Mexico are frequently analysed in isolation or excluded due to data constraints, despite their substantial contributions to global emissions, rapid urbanisation, and pronounced health inequalities (Tong et al., 2020; Onifade and Alola, 2022; Ge and Wu, 2025). The lack of multi-country evidence incorporating these economies restricts external validity and obscures heterogeneity in how green finance interacts with differing structural, institutional, and demographic contexts.

Third, while the environmental effectiveness of green finance is well established, the transmission mechanisms linking green finance to health outcomes remain underexplored. Most studies examine reduced emissions or improved environmental indicators as endpoints rather than intermediate channels affecting human welfare (Alharbi et al., 2023; Iacobuţă et al., 2022). Empirical work directly connecting environmental quality improvements to life expectancy and mortality outcomes exists (Beyene and Kotosz, 2021; Lawand et al., 2023; Landrigan et al., 2024), yet these insights are rarely integrated into formal mediation frameworks that jointly model green finance, environmental quality, and health. Moreover, health system resilience, which became especially salient during COVID-19, is largely absent from green finance–health analyses, despite evidence that climate-aligned investments can strengthen energy reliability, fiscal space, and adaptive capacity in health systems (Borghi et al., 2024; Teshome et al., 2023).

This study addresses these gaps in several important ways. First, it provides post-COVID empirical evidence on the relationship between green finance and human health outcomes by explicitly comparing pre-COVID (2000–2019) and COVID-era (2020–2023) dynamics. Second, it adopts a cross-country panel framework covering China, India, Brazil, Indonesia, and Mexico, thereby capturing heterogeneity across major emerging economies that are central to global climate and health trajectories. Third, it advances the literature by implementing a mediation framework in which environmental quality, proxied by CO_2 emissions, serves as a transmission channel linking public renewable-energy finance to life expectancy and under-5 mortality. By combining robust panel estimators with bootstrapped indirect effects, the study contributes methodologically and substantively to understanding how climate-focused investments shape human health in a period of compounded environmental and public health risks.

3. Materials and methods

3.1. Research design

This study adopts a quantitative panel research design to examine the relationship between green finance, environmental quality, and human health outcomes in selected emerging economies. The panel framework is particularly appropriate for capturing both temporal dynamics and cross-country heterogeneity in health, environmental, and macroeconomic indicators, while controlling for unobserved country-specific characteristics that remain constant over time.

Beyond estimating direct effects, the study explicitly incorporates a mediation perspective in which environmental quality is conceptualised as a potential transmission channel through which green finance influences population health. This framework reflects theoretical expectations that climate-focused public investment improves environmental conditions, notably through emissions reduction, which may subsequently affect health outcomes. The mediation approach allows the analysis to distinguish between direct health effects of green finance and indirect effects operating through environmental quality.

The study is conceptually aligned with the Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-Being), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). By focusing on public renewable-energy finance, the analysis highlights the potential co-benefits of climate-oriented financial interventions for environmental sustainability and public health. Improvements in environmental quality constitute a key mechanism through which green finance may contribute to SDG target 3.9, which seeks to reduce mortality and morbidity associated with hazardous environmental exposures, while simultaneously advancing energy transition and climate mitigation objectives.

3.2. Data sources, scope of study, and variable measurement

The empirical analysis is based on a balanced annual panel dataset covering Brazil, China, India, Indonesia, and Mexico over the period 2000–2023. These countries are selected on the basis of consistent data availability for public renewable-energy finance, environmental indicators, and health outcomes, as well as their relevance as major emerging economies characterised by rapid urbanisation, rising energy demand, and substantial emissions profiles. Collectively, they account for a significant share of global energy consumption and pollution-related health burdens, making them empirically relevant for assessing the health co-benefits of climate-aligned public investment.

Data are drawn from internationally recognised and methodologically harmonised sources, including the World Development Indicators (WDI), the World Health Organization (WHO), the International Renewable Energy Agency (IRENA), and the United Nations Development Programme (UNDP). The extended sample period enables an explicit comparison between the pre-COVID era (2000–2019) and the COVID period (2020–2023), consistent with recent journal practice that emphasises sub-sample estimation to capture structural breaks associated with the pandemic.

Human health outcomes constitute the dependent variables and align directly with SDG 3 (Good Health and Well-Being). Two complementary indicators are employed to capture both long-term and child-specific health conditions. Life expectancy at birth (lnLEXP) reflects overall population health and longevity, incorporating cumulative effects of environmental exposure, healthcare access, and socio-economic conditions. The under-5 mortality rate

(lnU5MR) captures child survival outcomes and is particularly sensitive to environmental quality, household living conditions, and public health infrastructure. Both variables are expressed in natural logarithms to stabilise variance and facilitate elasticity-based interpretation.

Table 1. Description, measurement, and sources of variables, source: Authors' compilation

Variable	Description	Measurement / Proxy	Data Sources	Relevant SDGs
Green Finance (GF)	Green Finance (GF) reflects public renewable energy finance flows, capturing investment commitments made by selected public financial institutions to support renewable energy projects. The variable represents the scale of climate-related public investment intended to facilitate energy transition, reduce dependence on fossil fuels and promote environmentally sustainable development.	Measured in million US dollars (USD million) at current prices. Values are rounded to the nearest one million, with amounts below USD 0.5 million recorded as zero. These data provide a consistent cross-country indicator of public green finance mobilisation.	IRENA, 2025	**SDG 7** (Affordable and Clean Energy); **SDG 13** (Climate Action)
Environmental Quality (EQ)	Condition of air and water quality in each country	• CO_2 emissions per capita	WDI	**SDG 12** (Responsible Consumption and Production); **SDG 13** (Climate Action)
GDP per Capita (GDPPC)	Level of economic development	Constant 2015 USD	WDI	**SDG 8** (Decent Work and Economic Growth)
Urbanisation Rate (URB)	Proportion of population living in urban areas	% of total population	WDI	**SDG 11** (Sustainable Cities and Communities)
Access to Electricity (ElecAcc)	Captures the extent to which the population has reliable access to electricity, reflecting infrastructure development, energy inclusion and a key channel through which renewable-energy investments can influence living conditions and health outcomes.	Percentage of total population with access to electricity (%)	WDI	**SDG 7** (Affordable and Clean Energy); **SDG 9** (Industry, Innovation and Infrastructure)
Under-5 Mortality Rate (U5MR)	Measures the probability of a child dying before reaching age five, reflecting overall population health status, quality of healthcare systems, and socio-economic conditions.	Number of deaths of children under age five per 1,000 live births	WDI	**SDG 3** (Good Health and Well-Being)
Life Expectancy at Birth (LEB)	Indicates the average number of years a newborn is expected to live if prevailing patterns of mortality at the time of birth remain constant, representing a broad measure of population health outcomes.	Life expectancy at birth, total (years)	WDI	**SDG 3** (Good Health and Well-Being)
Health Expenditure (HEXP)	Current health expenditure as a share of GDP provides an indication on the level of resources channelled to health relative to other uses. It shows the importance of the health sector in the whole economy and indicates the societal priority which health is given measured in monetary terms.	Current health expenditure (CHE) as percentage of gross domestic product (GDP) (%)	WHO	**SDG 3** (Good Health and Well-Being)
Education (Edu)	Represents the average number of completed years of formal education among the adult population (aged 25 and above), reflecting educational attainment, human capital development, and a key social determinant of health outcomes.	Average years of schooling of the population aged 25+ (years)	UNDP, Human Development Reports (HDR)	**SDG 4** (Quality Education); **SDG 3** (Good Health and Well-Being)

Green finance (lnGF) is the key explanatory variable and is closely aligned with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). It captures climate-focused public renewable-energy finance flows, reflecting investment commitments made by public financial institutions to support renewable-energy deployment.

These investments are intended to facilitate energy transition, reduce reliance on fossil fuels, and mitigate climate-related environmental risks. The variable is measured in million US dollars (USD) at current prices, rounded to the nearest million, with values below USD 0.5 million recorded as zero to ensure cross-country comparability.
Environmental quality (lnEQ) serves as the mediating variable and is proxied by CO_2 emissions, expressed in logarithmic form. This indicator is conceptually linked to SDG 12 (Responsible Consumption and Production) and SDG 13, as it reflects the carbon intensity of production and energy use. CO_2 emissions are employed due to their comprehensive coverage and continuity over the full sample period, particularly beyond 2020, when alternative air-pollution indicators such as $PM_{2.5}$ are unavailable for several countries. Higher CO_2 emissions indicate poorer environmental quality and greater exposure to pollution-related health risks.
The control vector captures macroeconomic and structural conditions that jointly influence environmental outcomes and population health, and which map onto broader SDG targets. GDP per capita (lnGDPpc), measured in constant 2015 US dollars, reflects overall economic development and is relevant to SDG 8 (Decent Work and Economic Growth), while also shaping fiscal capacity for health and environmental investment. Urbanisation (lnURB) captures the share of the population living in urban areas and is linked to SDG 11 (Sustainable Cities and Communities), reflecting both the potential health advantages of urban service access and the environmental pressures associated with dense settlement patterns. Education (lnEDU), proxied by average years of schooling among adults aged 25 and above, represents human capital development and is a key social determinant of health consistent with SDG 4 (Quality Education). Health expenditure (lnCHEXP), measured as current health expenditure as a percentage of GDP, captures public and private commitment to healthcare provision and directly supports SDG 3. Finally, access to electricity (lnELECACC) reflects energy infrastructure development and energy inclusion, linking SDG 7 and SDG 9 (Industry, Innovation and Infrastructure), and represents an important channel through which renewable-energy investment may improve living conditions and health outcomes.
A detailed description of all variables, their measurement, and data sources is provided in Table 1.

3.3. Justification of country selection

The choice of Brazil, China, India, Indonesia, and Mexico is guided by both data considerations and substantive relevance. These countries constitute the subset of major emerging economies for which consistent and comparable data on public renewable-energy finance and health outcomes are jointly available over a sufficiently long-time horizon. Each country exhibits high energy consumption, rapid urbanisation, and significant emissions levels, which are closely linked to pollution exposure and environmental health risks.
Furthermore, these economies have established policy frameworks and institutional mechanisms for mobilising climate-focused public investment, including renewable-energy programmes and emissions-mitigation initiatives. Their diverse development trajectories and energy structures enhance the external validity of the findings and allow for meaningful cross-country comparison.

3.4. Model specification

To address the research objectives, the study specifies two main modelling blocks.

Model A: Baseline effect of green finance on health

The baseline model examines whether green finance is associated with improvements in human health outcomes. For each health indicator, the following fixed-effects specification is estimated:

$$H_{it} = \alpha + \beta_1 GF_{it} + \beta_2 GDPpc_{it} + \beta_3 URB_{it} + \beta_4 EDU_{it} + \beta_5 CHEXP_{it} + \beta_6 ELECACC_{it} + \mu_i + \varepsilon_{it}$$

A positive value of $\beta_1$is expected when life expectancy is the dependent variable, while a negative value is expected when mortality indicators are used. Because access to electricity may itself represent a pathway through which renewable-energy investment affects health, specifications both excluding and including lnELECACC are considered, with the latter interpreted as a net-of-electrification effect.

Model B: Mediation through environmental quality

To assess whether environmental quality acts as a transmission mechanism linking green finance to health outcomes, a two-equation mediation framework is employed.

Model B1 (first stage):

$$EQ_{it} = \delta + \pi_1 GF_{it} + \pi_2 GDPpc_{it} + \pi_3 URB_{it} + \pi_4 EDU_{it} + \pi_5 CHEXP_{it} + \mu_i + u_{it}$$

Model B2 (second stage):

$$H_{it} = \alpha + \beta_1 GF_{it} + \beta_2 EQ_{it} + \beta_3 GDPpc_{it} + \beta_4 URB_{it} + \beta_5 EDU_{it} + \beta_6 CHEXP_{it} + \beta_7 ELECACC_{it} + \mu_i + \eta_{it}$$

The indirect (mediated) effect is computed as $IE = \pi_1 \times \beta_2$and evaluated using non-parametric bootstrap inference. When environmental quality is proxied by CO_2 emissions, $\pi_1 < 0$is expected if green finance reduces emissions. In the health equation, $\beta_2 < 0$is anticipated for life expectancy and $\beta_2 > 0$for mortality outcomes.

3.5. Diagnostic and pre-estimation tests

Prior to model estimation, a set of diagnostic and pre-estimation tests was conducted to evaluate the presence of multicollinearity, cross-sectional dependence, and heteroskedasticity, thereby informing the choice of appropriate estimation and inference techniques.

Multicollinearity was assessed using the Variance Inflation Factor (VIF). For Model A, estimated separately for life expectancy and under-5 mortality, the mean VIF is 7.06. Relatively high VIF values are observed for lnGDPpc (15.96) and lnURB (8.75), reflecting the expected co-movement among macro-development indicators in a small-country panel setting. Importantly, the VIF for the key explanatory variable, green finance (lnGF), is low at 1.60, indicating that inference on the primary variable of interest is not materially affected by multicollinearity. For the mediation first-stage equation (Model B1), the mean VIF is 6.50, with the maximum value again associated with lnGDPpc (11.86), while lnGF remains weakly correlated with the control variables (VIF = 1.43). Overall, these results suggest that although some degree of correlation exists among the controls, multicollinearity does not pose a serious threat to coefficient stability or statistical inference.

Cross-sectional dependence was examined using Pesaran's CD test, and the results indicate that dependence is specification-specific. For Model A with life expectancy as the dependent variable, the CD statistic is positive and statistically significant (CD = 5.296, p = 0.0000), consistent with the presence of common shocks or spillover effects across Brazil, China, India, Indonesia, and Mexico. In contrast, for Model A with under-5 mortality, the CD statistic is not statistically significant (CD = −1.429), suggesting that contemporaneous cross-country correlation is not sufficiently systematic to reject the null of cross-sectional independence for this outcome. For the mediation framework, the CD test for Model B1 indicates weak to moderate cross-sectional dependence that is marginally significant at conventional levels (CD = 1.856, p = 0.0634), implying some degree of shared environmental or policy-related dynamics across countries.

Heteroskedasticity was assessed using the Breusch–Pagan/Cook–Weisberg test. The null hypothesis of homoskedasticity is not rejected for the life expectancy equation ($\chi^2 = 1.80$, p = 0.1791) or for the environmental quality equation in Model B1 ($\chi^2 = 1.69$, p = 0.1938). However, the null is strongly rejected for the under-5 mortality specification ($\chi^2 = 11.29$, p = 0.0008), indicating the presence of heteroskedasticity in that model. Although a formal serial-correlation test statistic is not reported, the time-series dimension of the panel and the observed heteroskedasticity in at least one specification suggest that serial dependence is likely to be present.

Taken together, these diagnostic results point to a data structure characterised by outcome-specific cross-sectional dependence, heteroskedasticity, and potential serial correlation. These features motivate the use of estimation strategies that provide inference robust to these conditions and directly inform the choice of the baseline estimation techniques employed in the study.

3.6. Estimation techniques

Given the structure of the panel, comprising a small number of countries observed over a relatively long time horizon, the empirical analysis adopts a country fixed-effects estimator as the baseline specification. This approach controls for unobserved, time-invariant heterogeneity across Brazil, China, India, Indonesia, and Mexico that may jointly influence health outcomes, environmental conditions, and green investment patterns.

The diagnostic and pre-estimation tests reveal the presence of outcome-specific cross-sectional dependence, evidence of heteroskedasticity in selected specifications, particularly in the under-5 mortality model, and the likelihood of serial correlation inherent in macro-panel data. To ensure valid statistical inference under these conditions, all fixed-effects estimates are reported with Driscoll–Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and general forms of cross-sectional dependence. This estimator is particularly well suited to panels with a limited cross-sectional dimension and has been widely applied in empirical studies at the intersection of macroeconomics, environmental policy, and public health.

To assess the stability of the results under alternative treatments of cross-sectional correlation, Panel-Corrected Standard Errors (PCSE) are additionally reported as a robustness check. Feasible Generalised Least Squares (FGLS) is further employed as a sensitivity exercise to examine coefficient stability under alternative variance–covariance structures, while recognising that inference based on FGLS should be interpreted cautiously in panels with a small number of cross-sectional units.

In line with the study's focus on pandemic-related structural shifts, all baseline and mediation models are estimated separately for the pre-COVID period (2000–2019) and the COVID period (2020–2023) using the same fixed-effects framework. In addition, country-specific estimations for Brazil, China, India, Indonesia, and Mexico are conducted using time-series regressions with heteroskedasticity- and autocorrelation-consistent standard errors. The indirect effects in the mediation analysis are evaluated using a country-level non-parametric bootstrap procedure with 1,000 replications.

4. Results and discussion

4.1. Presentation of results

4.1.1. Descriptive statistics

Table 2 reports notable heterogeneity across countries in both health outcomes and the core explanatory variables. For the full sample, mean life expectancy is 71.75 years, ranging from 62.75 to 78.20, while under-5 mortality averages 28.98 deaths per 1,000 live births, with a wide span from 6.20 to 91.60. The dispersion in U5MR (SD = 18.46) is materially larger than that for LEXP (SD = 3.73), indicating that cross-country and intertemporal variability is far more pronounced for child survival outcomes than for longevity. This is consistent with the sensitivity of child mortality to changes in environmental risks, primary healthcare access, and household living conditions.

Environmental quality exhibits substantial variation. The full-sample mean of EQ is 3.24 (SD = 2.13), with a maximum of 9.40, suggesting that emissions intensity differs considerably across the panel. Country statistics point to marked differences in the emissions profile: EQ is lowest in Indonesia (mean 1.45) and India (mean 1.87) relative to Mexico (mean 4.02) and China (mean 2.90), highlighting heterogeneity in industrial structure and energy composition.

Green finance is highly dispersed both across countries and over time. The full-sample mean is USD 917.96 million with a very large standard deviation (1,783.00) and a maximum of USD 13,762.60 million, indicating pronounced volatility in public renewable-energy finance flows. China stands out with the highest mean green finance (USD 3,040.93 million) and the highest maximum, consistent with scale effects and a sustained programme of renewable-energy investment. By contrast, Brazil, Indonesia, and Mexico record substantially lower mean flows, while minimum values near zero in several countries indicate intermittent or low recorded public finance in some years. This distribution supports the use of logarithmic transformation in estimation to mitigate skewness and improve interpretability.

Macro-structural controls also show strong cross-country differences that matter for identification. GDP per capita averages USD 5,805.73 in the full sample, but ranges from mean values around USD 1,378.78 (Indonesia) to USD 9,720.81 (Mexico). Urbanisation is highest in Brazil (mean 84.68%) and Mexico (mean 78.23%) and lowest in Indonesia (mean 31.65%), reflecting distinct stages of structural transformation. Health expenditure as a share of GDP averages 4.99%, but is notably higher in Brazil (8.61%) than in India (2.71%). Electricity access is high on average (94.21%) but remains notably lower in Indonesia (mean 80.51%), suggesting that energy inclusion remains an important structural correlate of health outcomes in the panel.

Overall, the descriptive statistics confirm substantial heterogeneity across the five emerging economies in green finance mobilisation, emissions intensity, and health outcomes. This reinforces the suitability of a fixed-effects framework to net out time-invariant country characteristics, while also motivating country-specific estimations and sub-sample analysis around the COVID period.

Table 2. Descriptive statistics, source: Authors' computation

Variable	Full Sample		Brazil		China		India		Indonesia		Mexico	
	Mean	Min	Mean	Min	Min	Mean	Mean	Min	Mean	Min	Mean	Min
	(SD)	(Max)	(SD)	(Max)	(Max)	(SD)	(SD)	(Max)	(SD)	(Max)	(SD)	(Max)
EQ	3.24	0.94	2.24	1.92	6.62	2.90	1.45	0.94	1.87	1.38	4.02	3.37
	(2.13)	(9.40)	(0.23)	(2.73)	(2.04)	(9.40)	(0.36)	(2.05)	(0.31)	(2.40)	(0.25)	(4.33)
LEXP	71.75	62.75	73.44	69.58	75.78	72.29	67.45	62.75	68.51	65.52	73.56	69.75
	(3.73)	(78.20)	(1.92)	(75.85)	(1.90)	(78.20)	(2.76)	(72.00)	(1.47)	(71.15)	(1.21)	(75.07)
U5MR	28.98	6.20	20.18	14.40	16.70	6.20	55.70	27.70	33.44	20.60	18.87	12.50
	(18.46)	(91.60)	(6.07)	(34.50)	(9.31)	(36.70)	(20.25)	(91.60)	(9.87)	(51.90)	(4.63)	(28.10)
GF	917.96	0.12	3040.93	5.56	203.26	23.16	875.71	12.06	294.17	0.12	175.71	0.17
	(1,783.00)	(13,762.60)	(3,066.77)	(13,762.60)	(261.34)	(1,329.07)	(785.05)	(2,994.65)	(295.04)	(1,063.86)	(230.09)	(734.55)
GDPPC	5805.73	756.70	8305.04	6817.78	6720.21	2237.44	1378.78	756.70	2903.82	1828.10	9720.81	9074.12
	(3,545.38)	(12,484.16	(861.25)	(9,366.74)	(3,278.20)	(12,484.16)	(462.91)	(2,270.91)	(762.55)	(4,192.65)	(358.10)	(10,296.87)
Urban	59.20	27.67	84.68292	81.19	50.785	35.88	31.6538	27.67	50.6521	42	78.22542	74.72
	(20.24)	(87.79)	(2.03)	(87.79)	(8.96)	(64.57)	(2.65)	(36.36)	(5.10)	(58.57)	(2.10)	(81.58)
HealthExp	4.99	1.85	8.61	7.74	4.65	3.67	3.57	2.86	2.71	1.85	5.41	4.24
	(2.10)	(9.64)	(0.63)	(9.64)	(0.53)	(5.59)	(0.41)	(4.34)	(0.43)	(3.71)	(0.40)	(6.05)
EDU	7.074691	4.14268	7.04444	5.272178	7.179839	6.12	5.35525	4.14268	7.58857	5.95125	8.205356	6.66
	(1.25)	(9.35)	(1.00)	(8.43)	(0.63)	(8.04)	(0.85)	(6.88)	(0.77)	(8.70)	(0.82)	(9.35)
ElecACC	94.21	60.3	98.5625	94.4	99.08333	96.7	80.5083	60.3	93.9417	84.8	98.93333	97.1
	(9.53)	(100.00)	(1.52)	(100.00)	(1.18)	(100.00)	(13.38)	(99.60)	(4.83)	(100.00)	(0.80)	(100.00)

4.1.2. Correlation analysis

Tables 3–8 report pairwise correlations that provide preliminary insights into the direction of associations, while not implying causality. In the full sample (Table 3), life expectancy is strongly negatively correlated with under-5

mortality (r = −0.917), confirming that both indicators capture a common underlying health dimension. Life expectancy is positively associated with environmental quality proxy (CO_2) (r = 0.871) and GDP per capita (r = 0.852), while U5MR is negatively correlated with GDP per capita (r = −0.885) and education (r = −0.793). These patterns suggest that development and human capital improvements coincide with better health outcomes, as expected.

Notably, green finance exhibits weak contemporaneous correlations with health outcomes in the full sample (lnGF with lnLEXP: 0.059; lnGF with lnU5MR: −0.085), implying that any health effects of green finance may be indirect, lagged, or confounded by structural differences across countries. Green finance is negatively correlated with CO_2 (r = −0.210) at the full-sample level, which is directionally consistent with the premise that renewable-energy public finance can reduce emissions, but the magnitude is modest, supporting the subsequent need for multivariate fixed-effects estimation.

The country-level correlation matrices show meaningful heterogeneity in co-movements. In India and Indonesia (Tables 6–7), green finance correlates strongly with environmental quality (India: lnGF–lnEQ 0.781; Indonesia: 0.687), which may reflect investment responses to rising emissions or energy demand dynamics rather than immediate mitigation effects. Brazil shows a moderate positive correlation between lnGF and lnEQ (0.395), whereas Mexico exhibits a negative correlation (−0.290). These contrasts reinforce the relevance of estimating country-specific models and employing robust inference procedures, given that pooled correlations may mask structurally different policy and emissions regimes.

The correlation matrices also reveal strong associations among macro controls, particularly lnGDPPC and lnURB (full sample: 0.928), and lnEDU and lnELECACC (full sample: 0.818), suggesting the potential for multicollinearity among development-related covariates. This is consistent with our VIF diagnostics and supports careful interpretation of control coefficients while maintaining focus on the parameters of interest.

Table 3. Correlation analysis for the full sample, c

	lnLEXP	**lnU5MR**	**lnGF**	**lnEQ**	**lnGDPPC**	**lnURB**	**lnCHEXP**	**lnEDU**	**lnELECACC**
lnLEXP	1.000								
lnU5MR	-0.917	1.000							
lnGF	0.059	-0.085	1.000						
lnEQ	0.871	-0.846	-0.210	1.000					
lnGDPPC	0.852	-0.885	-0.031	0.729	1.000				
lnURB	0.640	-0.705	0.025	0.435	0.928	1.000			
lnCHEXP	0.568	-0.509	0.282	0.287	0.683	0.713	1.000		
lnEDU	0.643	-0.793	-0.030	0.584	0.744	0.693	0.186	1.000	
lnELECACC	0.784	-0.796	0.062	0.655	0.789	0.696	0.320	0.818	1.000

Table 4. Correlation analysis for Brazil**,** source: Authors' computation

	lnLEXP	**lnU5MR**	**lnGF**	**lnEQ**	**lnGDPPC**	**lnURB**	**lnCHEXP**	**lnEDU**	**lnELE-CACC**
lnLEXP	1.000								
lnU5MR	-0.956	1.000							
lnGF	0.541	-0.549	1.000						
lnEQ	0.738	-0.743	0.395	1.000					
lnGDPPC	0.920	-0.934	0.580	0.862	1.000				
lnURB	0.905	-0.970	0.413	0.663	0.853	1.000			
lnCHEXP	0.417	-0.493	-0.104	0.142	0.205	0.644	1.000		
lnEDU	0.919	-0.984	0.468	0.672	0.872	0.996	0.609	1.000	
lnELECACC	0.951	-0.971	0.617	0.743	0.926	0.913	0.406	0.936	1.000

Table 5. Correlation Analysis for China, source: Authors' computation

	lnLEXP	**lnU5MR**	**lnGF**	**lnEQ**	**lnGDPPC**	**lnURB**	**lnCHEXP**	**lnEDU**	**lnELE-CACC**
lnLEXP	1.000								
lnU5MR	-0.993	1.000							
lnGF	0.161	-0.146	1.000						
lnEQ	0.967	-0.946	0.094	1.000					
lnGDPPC	0.997	-0.996	0.155	0.968	1.000				
lnURB	0.997	-0.998	0.142	0.964	0.999	1.000			
lnCHEXP	0.768	-0.797	0.291	0.606	0.761	0.770	1.000		
lnEDU	0.997	-0.998	0.164	0.953	0.997	0.999	0.794	1.000	
lnELECACC	0.949	-0.920	0.173	0.983	0.950	0.941	0.611	0.932	1.000

Table 6. Correlation analysis for India, source: Authors' computation

	lnLEXP	lnU5MR	lnGF	lnEQ	lnGDPPC	lnURB	lnCHEXP	lnEDU	lnELE-CACC
lnLEXP	1.000								
lnU5MR	-0.940	1.000							
lnGF	0.728	-0.729	1.000						
lnEQ	0.966	-0.960	0.781	1.000					
lnGDPPC	0.962	-0.992	0.757	0.981	1.000				
lnURB	0.945	-0.999	0.732	0.963	0.994	1.000			
lnCHEXP	-0.825	0.788	-0.693	-0.834	-0.832	-0.796	1.000		
lnEDU	0.948	-0.998	0.745	0.969	0.994	0.998	-0.809	1.000	
lnELECACC	0.950	-0.990	0.745	0.976	0.994	0.991	-0.826	0.993	1.000

Table 7. Correlation analysis for Indonesia, source: Authors' computation

	lnLEXP	lnU5MR	lnGF	lnEQ	lnGDPPC	lnURB	lnCHEXP	lnEDU	lnELE-CACC
lnLEXP	1.000								
lnU5MR	-0.871	1.000							
lnGF	0.593	-0.672	1.000						
lnEQ	0.843	-0.968	0.687	1.000					
lnGDPPC	0.870	-0.995	0.675	0.972	1.000				
lnURB	0.857	-0.995	0.690	0.973	0.997	1.000			
lnCHEXP	0.566	-0.794	0.724	0.757	0.777	0.804	1.000		
lnEDU	0.789	-0.951	0.740	0.937	0.948	0.963	0.812	1.000	
lnELECACC	0.843	-0.948	0.626	0.931	0.960	0.958	0.771	0.885	1.000

Table 8. Correlation Analysis for Mexico, source: Authors' computation

	lnLEXP	lnU5MR	lnGF	lnEQ	lnGDPPC	lnURB	lnCHEXP	lnEDU	lnELE-CACC
lnLEXP	1.000								
lnU5MR	-0.042	1.000							
lnGF	-0.036	-0.567	1.000						
lnEQ	0.539	0.576	-0.290	1.000					
lnGDPPC	0.490	-0.614	0.395	-0.068	1.000				
lnURB	0.038	-1.000	0.573	-0.586	0.615	1.000			
lnCHEXP	-0.115	-0.568	0.149	-0.195	0.004	0.554	1.000		
lnEDU	0.043	-0.986	0.560	-0.494	0.591	0.983	0.634	1.000	
lnELECACC	0.068	-0.872	0.638	-0.372	0.629	0.870	0.493	0.873	1.000

4.1.3. Unit Root Tests

Table 9 presents panel unit root tests using Im–Pesaran–Shin (IPS) and Levin–Lin–Chu (LLC) procedures. The results suggest mixed integration orders across variables, which is typical in macro-panel settings. Life expectancy (lnLEXP) and environmental quality (lnEQ) are non-stationary in levels under both tests but become stationary after first differencing, implying integration of order one. GDP per capita (lnGDPPC), health expenditure (lnCHEXP), and education (lnEDU) similarly exhibit non-stationarity at levels and stationarity at first differences in at least one of the tests, supporting an I(1) character. In contrast, green finance (lnGF) is stationary in levels under both IPS and LLC, and urbanisation (lnURB) is stationary in levels under LLC. Electricity access (lnELE-CACC) also shows evidence of level stationarity under both tests.

Table 9. Unit Root Tests, source: Authors' computation

Variable	Im–Pesaran–Shin		Levin–Lin–Chu	
	I(0)	I(1)	I(0)	I(1)
lnLEXP	-0.053	-7.149***	-0.719	-7.8497***
lnU5MR	-1.159	-5.893***	-3.257***	-
lnGF	-4.039***	-	-4.967***	-
lnEQ	0.548	-6.101***	-0.913	-6.344***
lnGDPPC	1.868	-5.335***	0.718	-6.067***
lnURB	2.234	-5.907***	-2.465***	-
lnCHEXP	-0.318	-5.341***	-1.358*	-6.432***
lnEDU	3.855	-4.409***	3.740	-4.709***
lnELEACC	-1.754**	-	-1.526*	-12.343***

*** p<0.01, ** p<0.05, * p<0.1

Two implications follow for estimation. First, the presence of both I(0) and I(1) variables supports the use of fixed-effects models with robust inference, while maintaining attention to long-run relationships through cointegration testing. Second, the unit root outcomes provide justification for panel cointegration tests prior to interpreting the health and environmental equations as capturing long-run associations.

4.1.4. Panel Cointegration Test

Tables 10 and 11 report Pedroni and Kao cointegration tests for Models A and B. For Model A (Table 10), the Pedroni statistics provide strong evidence of cointegration in both health specifications: Phillips–Perron and Augmented Dickey–Fuller statistics reject the null at the one per cent level for both lnLEXP and lnU5MR equations. The modified Phillips–Perron statistic is also significant at conventional levels for the under-5 mortality specification (p = 0.025) and marginal for the life expectancy specification (p = 0.056). Kao tests are mixed in their adjusted forms, but the unadjusted modified Dickey–Fuller and unadjusted Dickey–Fuller statistics reject the null of no cointegration for both health outcomes, reinforcing the presence of a long-run relationship among the variables in Model A.

For Model B (Table 11), Pedroni tests indicate cointegration, with all three reported statistics significant (p-values between 0.001 and 0.010). The Kao test similarly shows mixed adjusted statistics, but the unadjusted modified Dickey–Fuller and unadjusted Dickey–Fuller statistics reject the null at the five per cent level. Collectively, these results support the interpretation that the variables in the mediation framework share a stable long-run association, providing an appropriate basis for estimating the environmental-quality and health equations within a fixed-effects framework and for computing indirect effects.

Table 10. Pedroni and Kao Panel Cointegration results for Model A, source: Authors' computation

	lnLEXP as Dependent Variable		**lnU5MR as Dependent Variable**	
	Statistic	**p-value**	**Statistic**	**p-value**
Pedroni Cointegration Test				
Modified Phillips–Perron t	1.589	0.056	1.965	0.025
Phillips–Perron t	-4.965	0.000	-4.454	0.000
Augmented Dickey–Fuller t	-4.949	0.000	-3.713	0.000
Kao Cointegration Test				
Modified Dickey–Fuller t	-0.111	0.456	-0.879	0.190
Dickey–Fuller t	-1.298	0.097	-1.108	0.134
Augmented Dickey–Fuller t	-0.863	0.194	-0.418	0.338
Unadjusted modified Dickey–Fuller	-9.581	0.000	-2.353	0.009
Unadjusted Dickey–Fuller t	-5.890	0.000	-1.830	0.034

Table 11. Pedroni and Kao Panel Cointegration results for Model B, source: Authors' computation

	Statistic	**p-value**
Pedroni Cointegration Test		
Modified Phillips–Perron t	3.272	0.001
Phillips–Perron t	2.991	0.001
Augmented Dickey–Fuller t	2.326	0.010
Kao Cointegration Test		
Modified Dickey–Fuller t	0.889	0.187
Dickey–Fuller t	0.202	0.420
Augmented Dickey–Fuller t	-0.396	0.346
Unadjusted modified Dickey–Fuller	-1.842	0.033
Unadjusted Dickey–Fuller t	-1.966	0.025

4.1.5. estimation results across methods

The empirical results for the study are presented for two interconnected modelling blocks. Model A evaluates the baseline association between green finance (public renewable-energy finance flows) and health outcomes, controlling for income, urbanisation, education, health spending, and electricity access (Table 12), and then explores heterogeneity through country-specific time-series estimates (Table 13) and pre-COVID versus COVID sub-sample estimates (Table 14). Model B tests the proposed environmental transmission mechanism by estimating (i) the effect of green finance on environmental quality proxied by CO_2 emissions (Model B1) and (ii) the joint effect of green finance and emissions on health outcomes (Model B2), followed by a bootstrap-based test of the mediated (indirect) effect (Tables 15–16). The variables and their measurement are defined in Table 1.

4.1.6. ***Model A:*** *Baseline effect of green finance on health*

4.1.6.1. Estimation results across methods

Table 12 reports full-sample fixed-effects estimates under Driscoll–Kraay (DK), with PCSE and FGLS used as complementary inference and sensitivity checks. Across methods, the green finance coefficient is not statistically significant for life expectancy (lnLEXP) and is generally small in magnitude. Under DK, lnGF is negative for lnLEXP (−0.0004) and positive but close to zero for lnU5MR (6.78E−05), both statistically insignificant. The PCSE estimates show a statistically significant negative coefficient for lnGF in the under-5 mortality equation (−0.0338, $p < 0.01$), suggesting that higher green finance is associated with lower under-5 mortality, but this result is not replicated under DK or FGLS. The lack of consistency in the green finance coefficient across estimators indicates that the direct health effect of public renewable-energy finance is not robust in pooled form, and that any influence may operate through other channels, vary across countries, or materialise with lags not captured by the contemporaneous specification.

In contrast, the control variables display more systematic patterns. GDP per capita enters with the expected signs across specifications, being positively and strongly associated with lnLEXP (DK: 0.175, $p < 0.01$; PCSE: 0.0927, $p < 0.01$; FGLS: 0.101, $p < 0.01$) and negatively associated with lnU5MR (PCSE: −1.036, $p < 0.01$; FGLS: −0.545, $p < 0.01$), consistent with development-driven improvements in population health. Education also shows a strong association with health, being positive and significant for life expectancy in DK (0.108, $p < 0.01$) and negative and significant for under-5 mortality across the three estimators. These results underscore the central role of human capital in shaping health outcomes in emerging economies.

The urbanisation coefficient is mixed across outcomes and estimators. Under DK, lnURB is negative and significant for lnLEXP (−0.439, $p < 0.01$) and also negative for lnU5MR (−1.474, $p < 0.01$), whereas PCSE and FGLS produce positive coefficients for lnURB in the lnU5MR equation. This divergence points to structural heterogeneity in the health consequences of urbanisation, where urban concentration can improve access to services in some contexts but also intensify congestion, pollution exposure, and inequalities in others. Health expenditure is similarly unstable across estimators and outcomes, suggesting that its relationship with population health is mediated by efficiency, targeting, and baseline disease burdens rather than spending levels alone. Electricity access is positive and significant for life expectancy in PCSE and FGLS, supporting the role of electrification as a welfare-enhancing infrastructural factor, though its sign and significance are not stable in the under-5 mortality equation.

Taken together, the full-sample evidence suggests that macro-structural drivers, especially income and education, dominate the baseline health gradients, whereas the direct contemporaneous association between green finance and health is weak and sensitive to estimator choice. This strengthens the motivation for (i) heterogeneity analysis and (ii) explicit mediation testing through environmental quality, as pursued in Model B.

Table 12. Regression results using Driscoll–Kraay, PCSE, and FGLS estimators for full sample, source: Authors' computation

VARIABLES	Driscoll-Kraay Standard Errors		Panel-Corrected Standard Errors (PCSE)		Feasible Generalised Least Squares (FGLS)	
	1	2	3	4	5	6
	lnLEXP	lnU5MR	lnLEXP	lnU5MR	lnLEXP	lnU5MR
lnGF	-0.0004	6.78E-05	0.0006	-0.0338***	-8.69E-05	-0.00243
	-0.00039	-0.00339	-0.00068	-0.00783	-0.00043	-0.0019
lnGDPPC	0.175***	-0.279*	0.0927***	-1.036***	0.101***	-0.545***
	-0.0413	-0.135	-0.00497	-0.065	-0.00726	-0.0669
lnURB	-0.439***	-1.474***	-0.170***	1.556***	-0.163***	0.680***
	-0.116	-0.498	-0.00752	-0.0853	-0.0167	-0.123
lnCHEXP	0.0121	0.162**	0.0418***	-0.190***	0.0207***	-0.258***
	-0.0195	-0.0677	-0.00749	-0.064	-0.00693	-0.0343
lnEDU	0.108***	-1.612***	0.0308*	-1.337***	0.00277	-1.391***
	-0.0175	-0.107	-0.0182	-0.0961	-0.0236	-0.0841
lnELECACC	0.0083	0.707***	0.134***	0.296	0.123***	-0.14
	-0.0373	-0.159	-0.0153	-0.226	-0.0259	-0.131
Constant	4.306***	11.13***	3.442***	7.361***	3.487***	8.814***
	-0.271	-1.362	-0.0545	-0.714	-0.0935	-0.434
Observations	**120**	**120**	**120**	**120**	**120**	**120**
Number of groups/c_d	**5**	**5**	**5**	**5**	**5**	**5**
R-squared			**0.938**	**0.953**		

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.1.6.2. Country-specific heterogeneity

Table 13 indicates that the green finance–health nexus is not uniform across Brazil, China, India, Indonesia, and Mexico, and that much of the cross-country variation is carried by the structural controls, which are themselves

policy-relevant. For life expectancy (lnLEXP), the coefficient on green finance (lnGF) varies in sign across countries and is statistically insignificant throughout, implying that the direct contemporaneous effect of public renewable-energy finance on longevity is not readily detectable at the country level within the model structure. For under-5 mortality (lnU5MR), the only statistically significant green finance coefficient occurs in Mexico, where lnGF is positive and significant (0.000519, $p < 0.01$). Taken at face value, this suggests that higher green finance coincides with higher under-5 mortality, which is not consistent with an immediate health co-benefit narrative. A more plausible interpretation is that this coefficient reflects timing and composition effects. Public renewable-energy finance may rise during periods of broader structural stress or reform, when health outcomes are influenced by concurrent macroeconomic adjustment, fiscal reprioritisation, inequality dynamics, or regional disparities in access to health services. It may also reflect that the health gains from energy-transition financing are often lagged, while under-5 mortality is sensitive to short-run shocks, nutrition, primary care access, and disease outbreaks. The Mexico result therefore should be framed as evidence that the health return to green finance is contingent on complementary social investments and health system resilience, rather than as a causal adverse effect.

The estimated coefficients on the controls provide clearer signals of the structural pathways shaping health outcomes and illuminate country-specific policy priorities.

Brazil: Under-5 mortality is strongly responsive to macro-development and demographic structure. lnGDPPC is negative and significant in the lnU5MR equation (−0.738, $p < 0.01$), while lnELECACC is negative and significant (−1.967, $p < 0.05$), indicating that improvements in household welfare and electrification are associated with lower child mortality. Conversely, lnURB is positive and significant (6.269, $p < 0.01$), suggesting that Brazil's urbanisation dynamics may be linked to spatial inequality, service congestion in informal settlements, or environmental health burdens that disproportionately affect children. Education also exhibits a large negative association with under-5 mortality (lnEDU: −2.141, $p < 0.01$). Taken together, Brazil's results point to a policy mix where urban public health infrastructure, child health outreach in peri-urban areas, and education-driven health literacy remain central, with electrification supporting improvements primarily through living conditions and service delivery.

China's coefficients are consistent with rapid structural transformation, but they also highlight the difficulty of separating development effects from health outcomes. lnGDPPC is negative and highly significant for under-5 mortality (−0.755, $p < 0.01$) and significant for life expectancy (−0.0339, $p < 0.01$), while lnCHEXP is negative and significant in both equations. These signs suggest that, within the time-series variation used for the country-specific regressions, higher income and health spending coincide with improved child survival, but the life expectancy result may reflect the way logged variables co-move during structural change rather than a simple marginal interpretation. Notably, lnELECACC is strongly positive and significant for lnU5MR (9.559, $p < 0.01$), which is unlikely to reflect a harmful effect of electrification per se and more likely reflects near-universal access and limited within-country variation, meaning the coefficient may be capturing broader time trends or multicollinearity with other development indicators. For China, the policy implication is less about marginal electrification gains and more about quality of health expenditure, ageing dynamics, and environmental management as the health burden shifts from communicable to non-communicable diseases.

India exhibits the expected pattern that child health is strongly shaped by demographic transition and social determinants. lnURB is negative and significant for both lnLEXP (−0.902, $p < 0.01$) and lnU5MR (−3.990, $p < 0.01$), suggesting that urbanisation, in India's case, may be associated with improved access to health services and lower child mortality, possibly reflecting urban advantages in maternal health care and immunisation coverage relative to rural areas. However, lnCHEXP is not significant, while lnGDPPC is positive and significant for lnLEXP (0.336, $p < 0.01$) but insignificant for lnU5MR, indicating that income improvements may translate more clearly into longevity than into immediate child survival once education and urbanisation are controlled for. This profile points to the continued importance of basic service delivery, education, and urban health governance, alongside targeted child and maternal health interventions, as key complements to energy-transition finance.

Indonesia's results highlight the role of structural development constraints and the importance of service access. Under-5 mortality declines with lnGDPPC (−0.500, $p < 0.10$) and is negatively associated with urbanisation (lnURB: −2.226, $p < 0.05$), while life expectancy is not strongly explained by income. Notably, lnCHEXP is weakly negative for lnLEXP (−0.0455, $p < 0.10$), which may indicate efficiency concerns or lagged returns to health spending rather than a direct adverse relationship. Electricity access reduces under-5 mortality (lnELECACC: 0.881, $p < 0.05$), though the sign is positive in your output; given typical interpretation, this again may reflect trend effects or limited within-country variation, and should be interpreted cautiously. The broader policy implication for Indonesia is that child survival remains highly responsive to structural improvements in living conditions and service access, implying that energy-transition finance is most likely to yield health gains when embedded within broader infrastructure and primary healthcare expansion.

Mexico shows the most distinct pattern. lnGDPPC is positive and significant for lnLEXP (0.363, $p < 0.01$) and negative and significant for lnU5MR (−0.0649, $p < 0.01$), while lnURB is strongly negative for lnU5MR (−8.584, $p < 0.01$). Education has the expected negative relationship with under-5 mortality (−0.0776, $p < 0.01$). Against this background, the positive lnGF coefficient on under-5 mortality suggests that green finance alone is not the binding constraint for child health outcomes in Mexico. Rather, the country's child health performance appears

more tightly linked to income, urban structure, and education, with the green finance signal likely reflecting confounding structural processes. For Mexico, the policy message is that energy-transition finance needs explicit social co-investments to generate measurable health co-benefits, particularly in vulnerable regions where child health outcomes remain sensitive to primary care capacity and household welfare.

Overall, the control-variable patterns reinforce a core inference: health co-benefits from public renewable-energy finance are unlikely to be automatic. They appear to depend on the maturity of health systems, the distributional consequences of urbanisation, education and human capital, and whether electrification translates into reliable, affordable, and clean energy services.

4.1.6.3. Structural change: pre-COVID versus COVID sub-samples

Table 14 provides sub-sample evidence that the green finance–health association changed during the pandemic period, with the clearest signal observed for under-5 mortality. For life expectancy, the green finance coefficient remains statistically insignificant in both eras and switches sign (pre-COVID: 0.000273; COVID: −0.0046). This pattern is consistent with the idea that, for a broad longevity measure, the short COVID window (2020–2023) is insufficient to capture the full adjustment through which renewable-energy finance may influence population health. It also reflects that life expectancy responds to cumulative health conditions and long-run improvements in living standards, so short-run disruptions can dominate marginal investment effects.

For under-5 mortality, green finance is negative and statistically significant in both periods (pre-COVID: −0.0344, $p < 0.01$; COVID: −0.0156, $p < 0.10$), indicating that higher public renewable-energy finance is associated with lower child mortality, although the magnitude attenuates in the COVID period. A plausible interpretation is that pandemic-related disruptions reduced the effectiveness of structural investments in translating into immediate child health gains. During 2020–2023, health service interruptions, income shocks, and strained public budgets likely weakened the marginal health returns to development-oriented investment flows, including green finance. The attenuation of the coefficient is therefore consistent with a pandemic-era environment where health-system constraints and household vulnerability became more binding.

The behaviour of the controls across sub-samples reinforces this interpretation. Income remains protective in both periods, with lnGDPPC positive and significant for life expectancy and strongly negative for under-5 mortality, indicating that macroeconomic conditions continued to be a dominant health driver. By contrast, several controls exhibit sign changes or reduced precision during COVID, particularly education and health expenditure, which is consistent with disruptions to schooling, reduced utilisation of routine health services, and shifts in health budgets towards emergency response. The lnCHEXP coefficient, for example, turns negative for life expectancy during COVID (−0.106, $p < 0.01$) while becoming positive and significant for under-5 mortality (0.358, $p < 0.01$), a pattern that is consistent with crisis-driven spending reallocations where expenditures increase but do not immediately translate into broader health improvements, especially for outcomes shaped by non-COVID care pathways.

In policy terms, the sub-sample results suggest that green finance may be more plausibly linked to child health-sensitive development improvements than to short-run changes in longevity, but that crisis periods can materially weaken this relationship unless green investment is coupled with resilient primary healthcare, child nutrition protection, and service continuity mechanisms. This interpretation also aligns with the heterogeneity evidence: countries where structural determinants such as education, urban structure, and income are stronger predictors of child health may require that energy-transition financing be integrated with explicit social policy instruments to achieve measurable health co-benefits.

Table 13. Country-specific estimates, source: estimated and compiled by the authors

VARIABLES	Brazil		China_		India		Indonesia		Mexico	
	1	2	3	4	5	6	7	8	9	10
	lnLEXP	lnU5MR	lnLEXP	lnU5MR	lnLEXP	lnU5MR	lnLEXP	lnU5MR	lnLEXP	lnU5MR
lnGF	0.000361	-0.0026	-0.000171	-0.000391	-0.00195	0.000291	0.00184	0.00443	-0.00085	0.000519***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
lnGDPPC	0.0706	-0.738***	-0.0339***	-0.755***	0.336***	-0.0154	0.0728	-0.500*	0.363***	-0.0649***
	(0.06)	(0.13)	(0.01)	(0.10)	(0.06)	(0.08)	(0.12)	(0.26)	(0.12)	(0.02)
lnURB	1.426	6.269***	0.00841	-1.966***	-0.902***	-3.990***	0.047	-2.226**	-0.0841	-8.584***
	(1.03)	(2.10)	(0.04)	(0.35)	(0.31)	(0.52)	(0.39)	(0.87)	(0.68)	(0.08)
lnCHEXP	-0.0076	-0.191	-0.00946***	-0.198***	0.0137	-0.0312	-0.0455*	-0.068	0.0332	-0.0643***
	(0.05)	(0.12)	(0.00)	(0.04)	(0.03)	(0.04)	(0.03)	(0.06)	(0.07)	(0.01)
lnEDU	-0.207	-2.141***	0.425***	1.416**	0.197	-0.211	-0.056	0.289	-0.022	-0.0776***
	(0.18)	(0.37)	(0.06)	(0.57)	(0.17)	(0.20)	(0.10)	(0.23)	(0.20)	(0.02)
lnELECACC	0.933**	-1.967**	0.467***	9.559***	-0.175	-0.034	0.0588	0.881**	-0.33	-0.142
	(0.37)	(0.97)	(0.06)	(0.64)	(0.12)	(0.09)	(0.15)	(0.36)	(0.66)	(0.11)
Constant	-6.536	-4.588	1.624***	-29.50***	5.345***	18.37***	3.346***	11.62***	2.839	41.85***
	(4.97)	(10.48)	(0.30)	(3.01)	(0.77)	(1.12)	(0.55)	(1.23)	(3.67)	(0.55)
Observations	24	24	24	24	24	24	24	24	24	24
Number of c_id	1	1	1	1	1	1	1	1	1	1

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 14. Pre-COVID and COVID Estimates for Model A, source: Estimated and compiled by the authors

VARIABLES	Using lnLEXP as Dependent variable		Using lnU5MR as Dependent variable	
	1	2	3	4
	Pre-COVID	COVID	Pre-COVID	COVID
lnGF	0.000273	-0.0046	-0.0344***	-0.0156*
	-0.000363	-0.00339	-0.00615	-0.00895
lnGDPPC	0.0813***	0.0852***	-0.927***	-1.306***
	-0.00375	-0.0178	-0.0636	-0.047
lnURB	-0.177***	0.239**	1.361***	0.671**
	-0.00542	-0.102	-0.0919	-0.269
lnCHEXP	0.0577***	-0.106***	-0.173**	0.358***
	-0.00444	-0.0405	-0.0753	-0.107
lnEDU	0.0780***	-0.739***	-1.139***	1.089**
	-0.00954	-0.183	-0.162	-0.482
lnELECACC	0.142***	-0.0447	-0.0482	2.219
	-0.0128	-0.531	-0.217	-1.402
Constant	3.415***	4.512*	8.408***	-1.642
	-0.0431	-2.41	-0.73	-6.356
Observations	**100**	**20**	**100**	**20**
Number of c_id	**5**	**5**	**5**	**5**

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.1.7. ***Model B:*** *Environmental quality as a transmission channel*

4.1.7.1. Model B1: Effect of green finance on environmental quality

Table 15 (Model B1) reports the first-stage relationship between green finance and environmental quality (CO_2 emissions per capita). The coefficient on green finance is negative (−0.00256) but statistically insignificant. This implies that, within the sample and controlling for income, urbanisation, health expenditure, and education, public renewable-energy finance does not produce a statistically detectable contemporaneous reduction in CO_2 emissions. In contrast, GDP per capita is positive and highly significant (1.127, $p < 0.01$), indicating that emissions rise with income-driven production expansion, consistent with scale effects in emerging economies. Urbanisation is weakly negative and marginally significant (−1.417, $p < 0.10$), suggesting that urban concentration may coincide with efficiency gains or structural shifts away from rural biomass reliance, although interpretation should remain cautious given the small N.

The first-stage results are crucial because they indicate that the proposed mechanism, *green finance reduces emissions*, is not strongly supported in the pooled specification. This has direct implications for the mediated effect.

4.1.7.2. Model B2: Joint effect of green finance and environmental quality on health

Table 15. Green Finance, Environmental Quality, and Health Outcomes: First- and Second-Stage Regression Results (Models B1 and B2), source: Estimated and compiled by the authors

VARIABLES	Model_B1	Model_B2	
	1	2	3
	lnEQ	lnLEXP	lnU5MR
lnGF	-0.00256	-0.000335	0.00102
	-0.00398	-0.000414	-0.00263
lnEQ		0.0248***	0.380***
		-0.00856	-0.1
lnGDPPC	1.127***	0.146***	-0.713***
	-0.194	-0.0335	-0.0948
lnURB	-1.417*	-0.403***	-0.922***
	-0.726	-0.105	-0.319
lnCHEXP	-0.0161	0.0127	0.171**
	-0.075	-0.0201	-0.0715
lnEDU	-0.0424	0.109***	-1.601***
	-0.0828	-0.0178	-0.107
lnELECACC		0.00915	0.720***
		-0.037	-0.177
Constant	-2.658**	4.368***	12.07***
	-1.252	-0.278	-1.279
Observations	120	120	120
Number of groups	5	5	5

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

In the second-stage health equations (Model B2), environmental quality is strongly associated with both health outcomes. CO_2 enters positively and significantly in the life expectancy equation (0.0248, $p < 0.01$) and positively and significantly in the under-5 mortality equation (0.380, $p < 0.01$). The positive sign for mortality is consistent with interpretation under our coding, where higher CO_2 reflects poorer environmental quality and thus worse child health outcomes. However, the positive sign for life expectancy is not consistent with the expected health-damaging role of emissions. This divergence suggests that, in this five-country sample, CO_2 may be capturing industrialisation and income-linked improvements that raise life expectancy through better living standards and health systems, even while increasing emissions. In other words, CO_2 is functioning as a composite indicator of structural transformation, which can generate opposing health signals depending on whether longevity or child mortality is used.

Importantly, once CO_2 is included in Model B2, the direct effect of green finance remains statistically insignificant for both health outcomes (lnLEXP: −0.000335; lnU5MR: 0.00102). This reinforces the interpretation from Model A that the direct contemporaneous effect of green finance on health is weak in pooled form.

4.1.7.3. Direct versus indirect effects: mediation evidence

Table 16 reports the bootstrapped indirect effects (IE = $\pi_1 \times \beta_2$) of green finance on health through environmental quality. For life expectancy, the indirect effect is −0.000064 ($p = 0.538$), while for under-5 mortality it is −0.000976 ($p = 0.435$). Both indirect effects are statistically insignificant. Substantively, this indicates that, as modelled with CO_2 as the environmental quality proxy, there is no evidence that green finance affects health outcomes through emissions reductions in the pooled sample.

The insignificance of the mediated effect follows logically from the weak first-stage relationship between green finance and emissions (Model B1), combined with the fact that the health association with CO_2 in Model B2 is not unambiguously aligned with the expected direction for longevity. The overall implication is that, within this dataset and specification, environmental quality proxied by CO_2 does not operate as a statistically validated transmission channel linking public renewable-energy finance to health outcomes. This does not rule out environmental mediation in principle; rather, it suggests that the channel may be obscured by (i) the macro scale effect of development on both emissions and health, (ii) the use of CO_2 as a broad emissions proxy rather than local exposure indicators, and (iii) heterogeneity across countries and time regimes.

Table 16. The mediated Effect Green Finance on Health Outcomes through Environmental Quality, source: Estimated and compiled by the authors

Variable	Indirect Effect (IE)	Bootstrap Std. Error	z-Statistic	p-Value
Green finance → CO_2 → Life expectancy	−0.000064	0.000103	−0.62	0.538
Green finance CO_2 → Under-5 Mortality Rate	-0.000976	0.0012487	-0.78	0.435

Notes: *The table reports the bootstrapped indirect (mediated) effect of green finance on health outcomes through environmental quality, proxied by CO_2 emissions. The indirect effect is computed as the product of the coefficient of green finance in the environmental quality equation and the coefficient of environmental quality in the life expectancy and under-5 mortality rate equations. Inference is based on a country-level cluster bootstrap with 1,000 replications.*

4.1.8. Synthesis of findings for Model A and Model B

Comparatively, the results yield three high-level insights. First, green finance does not exhibit a robust direct association with life expectancy across estimators, countries, or sub-samples, while its association with under-5 mortality is more supportive in the sub-sample analysis (Table 14) and under PCSE in the full sample (Table 12), though not consistently across all estimators. Second, green finance does not significantly reduce CO_2 emissions in the pooled first-stage model (Table 15), limiting the plausibility of emissions-based mediation. Third, the mediation tests confirm that the indirect effect of green finance through CO_2 is statistically insignificant for both health outcomes (Table 16), implying that the co-benefits of public renewable-energy finance for health, if present, are more likely to materialise through alternative pathways such as energy access, indoor air quality improvements, health-system strengthening, or longer-run structural transition dynamics not captured by contemporaneous CO_2 emissions.

Finally, the country-specific estimates demonstrate that the green finance–health association is not homogeneous across the five economies. The evidence points to context-specific effects, consistent with differences in energy structures, institutional capacity, baseline health conditions, and the composition of renewable-energy investment. This heterogeneity strengthens the case for cautious pooled interpretation and supports the study's inclusion of country-level results and COVID-era sub-sample analysis.

4.2. Discussion of results and findings

Our evidence provides nuanced answers to the study's research questions and clarifies where climate-focused public renewable-energy finance is most likely to matter for health in emerging economies. First, the pooled results

indicate that green finance does not exert a robust, contemporaneous effect on life expectancy, and its association with under-5 mortality is estimator- and regime-dependent rather than uniform. Second, the proposed environmental transmission mechanism, proxied CO_2 emissions, is not statistically supported: green finance does not significantly reduce CO_2 in the first stage, and the bootstrapped indirect effects on both life expectancy and under-5 mortality are insignificant. Third, the COVID-era sub-sample points to structural change, with the protective association between green finance and under-5 mortality weakening during 2020–2023. The novelty of the study lies in integrating a post-COVID sub-sample design with cross-country heterogeneity and a formal mediation test in a five-economy emerging-market panel, while focusing on public renewable-energy finance as a distinct component of green finance and examining both longevity and child survival outcomes that map closely to SDG 3 targets.

Placed in the context of prior work, these patterns partly align with the literature yet also highlight important tensions. The weak pooled direct effect of green finance on health is consistent with the idea that green finance operates primarily through environmental and structural channels that may take time to translate into measurable health outcomes, rather than producing immediate changes in broad indicators such as life expectancy (Sharma et al., 2022; Debrah et al., 2023; Ante, 2024). At the same time, the limited first-stage relationship between green finance and emissions contrasts with evidence that green financial flows reduce carbon emissions and support renewable-energy deployment in broader multi-country settings (Al Mamun et al., 2022; Zhang et al., 2022; Alharbi et al., 2023). This divergence is plausibly related to the specific nature of the present measure, public renewable-energy finance, and to the small-country panel setting, where CO_2 may reflect scale effects of growth and industrialisation more than marginal changes induced by renewable-energy finance (He et al., 2023; Behera et al., 2024). The strong associations of income and education with both health outcomes are consistent with long-established development-health gradients and with arguments that human capital and structural transformation remain central determinants of population health (Arun et al., 2023; Yu et al., 2022). In addition, the COVID-era attenuation in the green finance–under-5 mortality relationship resonates with evidence that COVID-19 reconfigured health systems, exposed inequalities, and altered the effectiveness of policy levers that would otherwise improve welfare outcomes (Shamasunder et al., 2020; Gostin et al., 2020; Büyüm et al., 2020).

The *why* and *how* of the results can be understood through the distinction between global emissions proxies and exposure-relevant environmental risks, as well as through the time profile of health responses. CO_2 is an economy-wide indicator of carbon intensity and production scale, but it does not directly capture local exposure to harmful air pollutants that drive the most immediate health burdens. The literature reviewed shows that environmental quality affects multiple physiological systems and that policy-driven improvements in environmental performance are associated with higher life expectancy and lower child morbidity and mortality (Sundas et al., 2024; Jain et al., 2024; Beyene and Kotosz, 2021; Lawand et al., 2023; Sidney Correa et al., 2024). In principle, green finance should contribute to these gains by shifting energy systems and reducing pollution. However, when environmental quality is proxied by CO_2, the measure can also move with industrial expansion that raises incomes and strengthens health systems, potentially increasing longevity even as emissions rise. This helps explain the counterintuitive positive association between CO_2 and life expectancy in Model B2, which likely reflects the co-movement of emissions with development and healthcare improvements rather than a protective role of emissions. Under-5 mortality, being more sensitive to short-run shocks and environmental conditions, exhibits a more policy-relevant response pattern, including the negative association with green finance in the pre-COVID and COVID sub-samples.

The *so what* for policy, especially in relation to SDGs, is that public renewable-energy finance is not a stand-alone health intervention, but it can still support SDG 3 when embedded within complementary structural policies that shape exposure pathways and service delivery. The strongest and most consistent predictors of improved health in the pooled models are GDP per capita and education, both of which are closely tied to SDG 4 (quality education) and the enabling conditions for SDG 3 outcomes. In this setting, the role of green finance is more plausibly indirect: it supports SDG 7 (clean energy) and SDG 13 (climate action) through energy transition, and the health co-benefits in SDG 3 are likely to emerge when the transition reduces pollution exposure, improves household energy conditions, and supports service reliability in healthcare delivery. This interpretation is consistent with evidence that clean energy access improves life expectancy and reduces disease prevalence through improved air quality and living conditions (Roy, 2024; Li et al., 2022; Zhou et al., 2025), and with findings that environmental *greenness* is associated with lower child mortality (Zhang et al., 2024). It also suggests that policy evaluation should track exposure-relevant outcomes and distributional patterns, rather than relying solely on CO_2 and contemporaneous population averages.

Heterogeneity results reinforce the need for country-specific policy framing. The absence of significant green finance coefficients for life expectancy across countries suggests that longevity gains are driven mainly by structural determinants and that green finance effects may be delayed or mediated through unobserved channels. The Mexico result, where green finance is positively associated with under-5 mortality, should not be read as evidence that green finance worsens child health. A more cautious interpretation is that green finance may have expanded during periods of broader macro-adjustment or in response to stressors affecting child health, producing a spurious

contemporaneous correlation. This aligns with the broader COVID-era literature highlighting that crisis conditions can distort standard relationships and amplify inequities (Shamasunder et al., 2020; Büyüm et al., 2020). For policy, the implication is that SDG-aligned green finance programmes should be paired with targeted child and maternal health interventions and equity-sensitive urban planning, given that urbanisation dynamics can either improve service access or intensify congestion and exposure risks depending on the national context (Ge and Wu, 2025; Tong et al., 2020). Importantly, the controls indicate that education and income effects remain powerful across contexts, suggesting that integrated strategies combining green investment with social investments are more likely to yield measurable SDG 3 dividends.

The COVID sub-sample evidence offers additional insight into resilience and the conditions under which green finance can translate into health improvements. The weakening of the negative green finance coefficient on under-5 mortality during 2020–2023 suggests that pandemic-era disruptions reduced the marginal returns of structural investment flows for child health. This aligns with evidence that governance fragmentation and institutional stress shaped health outcomes during COVID-19 (Gostin et al., 2020) and that environmental exposure amplified pandemic severity (Pansini and Fornacca, 2020; Maheswari et al., 2020; Weaver et al., 2022). It also supports the argument that climate-aligned finance can contribute to health system recovery and resilience only when institutional design and implementation capacity enable co-benefits to materialise (Borghi et al., 2024; Teshome et al., 2023). For SDG alignment, this highlights that progress on SDG 3 in crisis periods is contingent on resilience-oriented investments, while SDG 13 finance that does not explicitly incorporate health-system continuity may deliver weaker welfare returns during shocks.

Several strengths of the study enhance confidence in the interpretation, while clear limitations require careful framing. A key strength is the multi-layered empirical strategy that combines pooled estimation with country-specific heterogeneity and pre-COVID versus COVID sub-sample comparisons, consistent with the structural-break nature of the pandemic and the likelihood of context-specific slopes. The use of two distinct health outcomes, life expectancy and under-5 mortality, also strengthens inference by capturing both long-run health status and a child-sensitive outcome that responds more rapidly to environmental and socio-economic conditions. In addition, the mediation test with bootstrapped indirect effects provides a transparent assessment of the hypothesised mechanism rather than inferring it from separate regressions.

However, the study's limitations are equally important. First, the panel contains only five countries, which constrains statistical power and may limit the generalisability of pooled estimates. Second, CO_2 is an imperfect proxy for environmental quality in a health context, because it captures macro emissions and production scale rather than local pollutant exposure that more directly affects morbidity and mortality; this limitation is reflected in the sign divergence for life expectancy in Model B2. Third, the models are contemporaneous and may not capture lagged effects of renewable-energy investments on emissions, exposure, and health outcomes. Fourth, the country-specific results rely on time-series variation that may be sensitive to co-trending among macro variables, making some coefficients difficult to interpret causally. These constraints mean the findings should be interpreted as evidence about associations within the modelled structure, not definitive causal impacts.

The central message is that climate-focused public renewable-energy finance, on its own and in the short run, does not generate uniform improvements in population health across major emerging economies, and the CO_2-based mediation pathway is not empirically validated in the pooled sample. Nevertheless, the evidence suggests that child health may be more responsive than longevity to green finance during normal times, but that shocks such as COVID-19 can weaken this relationship. Policy design should therefore align SDG 7 and SDG 13 investments with explicit SDG 3 co-benefit strategies, prioritising mechanisms that reduce harmful exposure, protect child health during crises, and strengthen service reliability. Next steps for research, consistent with the literature reviewed, include testing alternative environmental mediators more closely linked to exposure and health risks, examining lag structures of green investment, and evaluating distributional effects to understand whether climate-aligned finance narrows or widens health inequities in emerging economies (Li et al., 2022; Zhang et al., 2024; Virparia et al., 2025; Borghi et al., 2024).

5. Conclusions

This study set out to examine whether climate-focused public renewable-energy finance contributes to improved human health outcomes in emerging economies, with particular emphasis on China and India, while explicitly accounting for environmental quality as a potential transmission channel and the structural disruption introduced by the COVID-19 pandemic. By integrating baseline panel estimates, country-specific heterogeneity, pre- and post-COVID comparisons, and a formal mediation framework, the analysis sought to move beyond broad claims about green finance to identify where, how, and under what conditions health co-benefits are likely to arise.

The findings provide a cautious but informative picture. In pooled terms, public renewable-energy finance does not exhibit a robust contemporaneous association with life expectancy, and its relationship with under-5 mortality is sensitive to estimator choice and time regime. While some evidence points to a protective association for child mortality, particularly before COVID-19, this effect weakens during the pandemic period. Environmental quality,

proxied by CO_2 emissions, does not mediate the green finance–health relationship in a statistically significant way, reflecting both the weak first-stage association between green finance and emissions and the dual role of emissions as an indicator of structural development rather than direct exposure. Across countries, income, education, and urbanisation patterns emerge as more consistent drivers of health outcomes than green finance alone, underscoring the primacy of macro-structural and human-capital factors.

These results matter for both policy and scholarship. They suggest that green finance should not be viewed as an automatic or stand-alone instrument for improving population health, but rather as part of a broader development and resilience strategy. When aligned with clean energy access, education, effective urban governance, and resilient health systems, climate-focused finance can support progress towards SDG 7 and SDG 13, while creating enabling conditions for SDG 3 gains, particularly in child health. The evidence also highlights who benefits most: populations whose health outcomes are closely tied to service access, living conditions, and exposure risks, rather than aggregate longevity measures that adjust slowly over time.

Looking ahead, future research should prioritise longer time horizons to capture lagged health effects of renewable-energy investments, employ exposure-relevant environmental indicators beyond CO_2, and examine distributional impacts across income groups, regions, and age cohorts. Expanding country coverage and integrating direct measures of health system resilience would further strengthen inference. Together, these directions can help refine climate finance design so that environmental objectives and human health outcomes are jointly realised in emerging economies facing increasing climate and public health risks.

References

1. AL MAMUN M., BOUBAKER S., NGUYEN D. K., 2022, Green finance and decarbonization: Evidence from around the world, *Finance Research Letters* 46: 102807, https://doi.org/10.1016/j.frl.2022.102807.
2. ALHARBI S. S., AL MAMUN M., BOUBAKER S., RIZVI S. K. A., 2023, Green finance and renewable energy: A worldwide evidence, *Energy Economics* 118: 106499, https://doi.org/10.1016/j.eneco.2022.106499.
3. ANSER M. K., HANIF I., VO X. V., ALHARTHI M., 2020, The long-run and short-run influence of environmental pollution, energy consumption, and economic activities on health quality in emerging countries, *Environmental Science and Pollution Research* 27(26): 32518–32532, https://doi.org/10.1007/s11356-020-09348-1.
4. ANTE L., 2024, The scope of green finance research: Research streams, influential works and future research paths, *Ecological Economics* 224: 108302, https://doi.org/10.1016/j.ecolecon.2024.108302.
5. ARUN G., GARUD S. K., KUMAR SHARMA C., 2023, Analysing the effects of environmental changes on public health quality indicators, *Health Leadership and Quality of Life* 2: 243, https://doi.org/10.56294/hl2023243.
6. BAŞTÜRK M. F., 2024, Does green finance reduce carbon emissions? Global evidence based on system generalized method of moments, *Sustainability* 16(18): 8210, https://doi.org/10.3390/su16188210.
7. BEHERA B., BEHERA P., SETHI N., 2024, Decoupling the role of renewable energy, green finance and political stability in achieving the sustainable development goal 13: Empirical insight from emerging economies, *Sustainable Development* 32(1): 119–137, https://doi.org/10.1002/sd.2657.
8. BEYENE S. D., KOTOSZ B., 2021, Empirical evidence for the impact of environmental quality on life expectancy in African countries, *Journal of Health and Pollution* 11(29): 210312, https://doi.org/10.5696/2156-9614-11.29.210312.
9. BORGHI J., GARCIA-DORADO S. C., ANTON B., GASPARTI G., HANSON M., SOUCAT A., BUSTREO F., LANGLOIS E., 2024, Climate finance opportunities for health and health systems, *Bulletin of the World Health Organization* 102(5): 330–335, https://doi.org/10.2471/BLT.23.290785.
10. BUGDEN D., 2022, Technology, decoupling, and ecological crisis: Examining ecological modernization theory through patent data, *Environmental Sociology* 8(2): 228–241, https://doi.org/10.1080/23251042.2021.2021604.
11. BÜYÜM A. M., KENNEY C., KORIS A., MKUMBA L., RAVEENDRAN Y., 2020, Decolonising global health: If not now, when?, *BMJ Global Health* 5(8): e003394, https://doi.org/10.1136/bmjgh-2020-003394.
12. CORADA K., COLLINS C.M., WOODWARD H., de NAZELLE A.,2021, Promoting a better understanding of green infrastructure in urban planning to reduce air pollution exposure, *ISEE Conference Abstracts* 2021(1): isee.2021.P-235, https://doi.org/10.1289/isee.2021.P-235.
13. CORREA F.C., PARMAR Y., AHMED W., ZAGADE T., SHARMA A., 2024, The influence of environmental policies on public health outcomes, *Health Leadership and Quality of Life* 3, https://doi.org/10.56294/hl2024.370.
14. DEBRAH C., DARKO A., CHAN A. P. C., 2023, A bibliometric-qualitative literature review of green finance gap and future research directions, *Climate and Development* 15(5): 432–455, https://doi.org/10.1080/17565529.2022.2095331.
15. EISENBERG J. N. S., DESAI M. A., LEVY K., BATES S. J., LIANG S., NAUMOFF K., SCOTT J. C., 2007, Environmental determinants of infectious disease: A framework for tracking causal links and guiding public health research, *Environmental Health Perspectives* 115(8): 1216–1223, https://doi.org/10.1289/ehp.9806.
16. EWING J. A., 2017, Hollow ecology: Ecological modernization theory and the death of nature, *Journal of World-Systems Research* 23(1): 126–155, https://doi.org/10.5195/jwsr.2017.611.
17. GE X., WU H., 2025, Public health policy pathways for balancing ecological challenges, healthcare systems, and social development in rapidly urbanizing economies, *Frontiers in Public Health* 13: 1716258, https://doi.org/10.3389 fpubh.2025.1716258.
18. GLAZENER A., KHREIS H., 2019, Transforming our cities: Best practices towards clean air and active transportation, *Current Environmental Health Reports* 6(1): 22–37, https://doi.org/10.1007/s40572-019-0228-1.
19. GOLLOPENI K. S., MAZLLAMI J., 2024, The impact of green finance on environmental protection, *Multidisciplinary Science Journal* 6(11): 2024220, https://doi.org/10.31893/multiscience.2024220.

20. GOSTIN L. O., MOON S., MEIER, B. M., 2020, Reimagining global health governance in the age of COVID-19, *American Journal of Public Health* 110(11): 1615–1619, https://doi.org/10.2105/AJPH.2020.305933.
21. HAILEMARIAM A., IVANOVSKI K., DZHUMASHEV R., 2022, Does R&D investment in renewable energy technologies reduce greenhouse gas emissions?, *Applied Energy* 327: 120056, https://doi.org/10.1016/j.apenergy.2022.120056.
22. HE X., KHAN S., OZTURK I., MURSHED M., 2023, The role of renewable energy investment in tackling climate change concerns: Environmental policies for achieving SDG 13, *Sustainable Development* 31(3): 1888–1901, https://doi.org/10.1002/sd.2491.
23. HEWITT C. N., ASHWORTH K., MACKENZIE A. R., 2020, Using green infrastructure to improve urban air quality (GI4AQ), *Ambio* 49(1): 62–73, https://doi.org/10.1007/s13280-019-01164-3.
24. IACOBUȚĂ G. I., BRANDI C., DZEBO A., LIZALDE DURON S. D., 2022, Aligning climate and sustainable development finance through an SDG lens: The role of development assistance in implementing the Paris Agreement, *Global Environmental Change* 74: 102509, https://doi.org/10.1016/j.gloenvcha.2022.102509.
25. JOSHIPURA M., NASRALLAH N., KEDIA N., 2025, Green and climate finance for sustainability: Hybrid review and framework development, *Business Strategy and the Environment* 34(3): 3618–3634, https://doi.org/10.1002/bse.4173.
26. KHOSLA R., KAMAT A. S., NARAYANAMURTI V., 2020, Successful clean energy technology transitions in emerging economies: Learning from India, China, and Brazil, *Progress in Energy* 2(4): 043002, https://doi.org/10.1088/2516-1083/abb52b.
27. LANDRIGAN P. J., BRITT M., FISHER S., HOLMES A., KUMAR M., Mu J., RIZZO I., SATHER A., YOUSUF A., KUMAR P., 2024, Assessing the human health benefits of climate mitigation, pollution prevention, and biodiversity preservation, *Annals of Global Health* 90(1): 1, https://doi.org/10.5334/aogh.4161.
28. LAWAND S., AWASTHI S., DAS, C., 2023, The effects of enhancements in environmental health on pediatric health outcomes, *Health Leadership and Quality of Life* 2: 259, https://doi.org/10.56294/hl2023259.
29. LEAL P. H., MARQUES A. C., SHAHBAZ M., 2023, Does climate finance and foreign capital inflows drive de-carbonisation in developing economies?, *Journal of Environmental Management* 347: 119100, https://doi.org/10.1016/j.jenvman.2023.119100.
30. LEE C.-C., LI X, YU C-H, ZHAO J., 2022, The contribution of climate finance toward environmental sustainability: New global evidence, *Energy Economics* 111: 106072, https://doi.org/10.1016/j.eneco.2022.106072.
31. LI, F., LIANG, W., CHANDIO, A. A., ZANG, D., & DUAN, Y., 2022, Household clean energy consumption and health: Theoretical and empirical analysis. *Frontiers in Public Health* 10: 945846. https://doi.org/10.3389/fpubh.2022.945846
32. LUO Y., TIAN S., YANG H., 2021, Green bonds, air quality, and mortality: Evidence from the People's Republic of China, *Asian Development Bank Working Paper,* https://doi.org/10.22617/WPS210435-2.
33. MAHESWARI S., PETHANNAN R., SABARIMURUGAN S., 2020, Air pollution enhances susceptibility to novel coronavirus (COVID-19) infection – an impact study, *Environmental Analysis Health and Toxicology* 35(4): e2020020, https://doi.org/10.5620/eaht.2020020.
34. MIAO M., BOROJO D. G., YUSHI J., 2025, Does climate finance really affect ecological quality in developing countries? Fresh evidence from the method of moments quantile regression approach, *International Journal of Finance & Economics* 30(4): 3431–3456, https://doi.org/10.1002/ijfe.3071.
35. NUMAN U., BENJIANG M., SADIQ M., BEDRU H.D., JIANG C., 2023, The role of green finance in mitigating environmental degradation: Empirical evidence and policy implications from complex economies, *Journal of Cleaner Production* 400: 136693, https://doi.org/10.1016/j.jclepro.2023.136693.
36. ONIFADE S. T., ALOLA A. A., 2022, Energy transition and environmental quality prospects in leading emerging economies: The role of environmental-related technological innovation, *Sustainable Development* 30(6): 1766–1778, https://doi.org/10.1002/sd.2346.
37. PANSINI R., FORNACCA D., 2020, COVID-19 higher induced mortality in Chinese regions with lower air quality, *Epidemiology,* https://doi.org/10.1101/2020.04.04.20053595.
38. RAY S., GANGULY R., 2024, The link between life expectancy, infant mortality rate and health expenditure: A global perspective, *International Journal of Social Science and Economic Research* 9(7): 2503–2510, https://doi.org/10.46609/IJSSER.2024.v09i07.027.
39. ROY A., 2025, A panel data study on the role of clean energy in promoting life expectancy, *Dialogues in Health* 6: 100201, https://doi.org/10.1016/j.dialog.2024.100201,
40. SHAMASUNDER S., HOLMES S.M., GORONGA T., CARRASCO H., KATZ E., FRANFURTER R., KESHAVJEE S., 2020, COVID-19 reveals weak health systems by design: Why we must re-make global health in this historic moment, *Global Public Health* 15(7): 1083–1089, https://doi.org/10.1080/17441692.2020.1760915.
41. SHARMA G. D., VERMA M., SHAHBAZ M., GUPTA M., CHOPRA R., 2022, Transitioning green finance from theory to practice for renewable energy development, *Renewable Energy* 195: 554–565, https://doi.org/10.1016/j.renene.2022.06.041.
42. SU Y., LEE C., 2025, Green finance, environmental quality and technological innovation in China. *International Journal of Finance & Economics* 30(1): 405–425. https://doi.org/10.1002/ijfe.2924
43. SUN Y., GUAN W., CAO Y., BAO Q., 2022, Role of green finance policy in renewable energy deployment for carbon neutrality: Evidence from China, *Renewable Energy* 197: 643–653, https://doi.org/10.1016/j.renene.2022.07.164.
44. SUNDAS, A., CONTRERAS I., MUJAHID O., BENEYTO A., VEHI J., 2024, The effects of environmental factors on general human health: A scoping review, *Healthcare* 12(21): 2123, https://doi.org/10.3390/healthcare12212123.
45. TESHOME M., 2023, The transformative role of adaptation strategies in designing climate-resilient and sustainable health systems, *Journal of Prevention* 44(5): 603–613, https://doi.org/10.1007/s10935-023-00740-4.
46. TONG T., ORTIZ J., XU C., LI F., 2020, Economic growth, energy consumption, and carbon dioxide emissions in the E7 countries: A bootstrap ARDL bound test, *Energy, Sustainability and Society* 10(1): 20, https://doi.org/10.1186/s13705-020-00253-6.

47. VIRPARIA V., BHATT O., PANCHAL N., 2025, Bridging finance and sustainability: A cross-country analysis of green investments in South Asia, *Emerging Frontiers in Management and Leadership*: 137–149, https://doi.org/10.51767/ic250212.
48. WEAVER A. K., HEAD J. R., GOULD C. F., CARLTON E. J., REMAIS J. V., 2022, Environmental factors influencing COVID-19 incidence and severity, *Annual Review of Public Health* 43(1): 271–291, https://doi.org/10.1146/annurev-publhealth-052120-101420.
49. YANG Z., ZHANG M., LIU L., ZHOU D., 2022, Can renewable energy investment reduce carbon dioxide emissions? Evidence from scale and structure, *Energy Economics* 112: 106181, https://doi.org/10.1016/j.eneco.2022.106181.
50. YU Y., ALVI S., TUFAIL S., NAEEM NAWAZ S.M., YAO-PING PENG M., AHMAD N., 2022, Investigating the role of health, education, energy and pollution for explaining total factor productivity in emerging economies, *Humanities and Social Sciences Communications* 9(1): 79, https://doi.org/10.1057/s41599-022-01083-x.
51. YU Z., YANG G., LIN T., ZHAO B., Xu Y., TAO X., MA W., VEJRE H., JIANG B., 2024, Exposure ecology drives a unified understanding of the nexus of (urban) natural ecosystem, ecological exposure, and health, *Ecosystem Health and Sustainability* 10: 0165, https://doi.org/10.34133/ehs.0165.
52. ZHANG K. Q., CHEN H. H., TANG L. Z., QIAO S., 2022, Green finance, innovation and the energy–environment–climate nexus, *Frontiers in Environmental Science* 10: 879681, https://doi.org/10.3389/fenvs.2022.879681.
53. ZHANG, L., WANG Q., LEI R., LIN J., GONG J., WANG L., XIE K., ZHENG X., XU K., ZHANG P., WU Y., ZENG X., MENG X. HAIDONG K., 2024, Greenness on mortality of infant and under-5 child: A nationwide study in 147 Chinese cities, *Ecotoxicology and Environmental Safety* 286: 117184, https://doi.org/10.1016/j.ecoenv.2024.117184.
54. ZHOU L., WU Y., TIAN X., 2025, From clean energy to clean air: Assessing the health outcomes of Northern China's clean energy initiatives, *Applied Ecology and Environmental Research* 23(6): 11597–11618, https://doi.org/10.15666/aeer/2306_1159711618.