MANAGING SOCIO-ECOLOGICAL RISKS IN E7 COUNTRIES: THE IMPACT OF PM2.5, ENVIRONMENTAL POLICIES, AND ECONOMIC DIVERSIFICATION ON LIFE EXPECTANCY

HE, X. D.[1] – HU, X. L.[2,3*] – BRIKA, S. K.[4]

[1]*School of Accounting, Guangzhou College of Technology and Business, Foshan 528138, China (e-mail: hexiaodong@gzgs.edu.cn)*

[2]*School of Accounting, Guangzhou College of Commerce, Guangzhou 511363, China*

[3]*Faculty of Finance, City University of Macau, Macau 999078, China*

[4]*Department of Administrative Sciences, Applied College, University of Bisha, Bisha 61922, Saudi Arabia (e-mail: sbrika@ub.edu.sa)*

**Corresponding author e-mail: F23092100176@cityu.edu.mo*

(Received 4th Sep 2025; accepted 17th Nov 2025)

Abstract. Strengthening health resilience is essential for sustainable development, particularly in emerging economies where rapid industrialization and urban expansion create complex socio-ecological challenges. Among these challenges, fine particulate matter (PM2.5) has emerged as a critical threat, linking environmental degradation to adverse health outcomes. This study investigates how PM2.5 air pollution, economic complexity, human capital development, health expenditure, environmental taxation, and urbanization interact to affect life expectancy across the E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) over the period 2000–2022. Advanced second-generation panel econometric techniques are employed, including the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model, supported by Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG) estimators, to capture both short- and long-run effects while addressing cross-sectional dependencies. The findings reveal that rising PM2.5 concentrations significantly decrease life expectancy, demonstrating that ecological stress directly undermines human well-being. Conversely, higher health expenditure, stronger human capital development, environmental taxation, and economic diversification enhance resilience by improving health outcomes. Rapid, unplanned urbanization intensifies PM2.5 exposure, amplifying socio-ecological risks. These results underscore the urgent need for integrated strategies that combine strict air quality management, sustainable urban planning, and social investments to reduce ecological pressures and build health-resilient societies in the face of accelerating environmental and demographic transitions.
Keywords: *health resilience, integrated policy frameworks, clean energy transition, environmental taxation, urban health challenges, environmental health governance*

Introduction

Improving population health and extending life expectancy have become central priorities for emerging economies striving for sustainable development. The E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) are among the world's most dynamic growth centers but continue to face mounting environmental, economic, and social pressures that directly influence population well-being (Su et al., 2020). While these nations achieved considerable economic progress, they struggle to balance economic expansion, with environmental quality and social welfare (Arbeláez-Rendón et al., 2023).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

A key yet underexplored driver of sustainable health outcomes is Economic Complexity (EC). EC reflects the technological knowledge and productive sophistication embedded in an economy (Poncet and Starosta de Waldemar, 2013). While industrialization and economic upgrading typically increase environmental pressures in the short run (Spash, 2007), higher economic complexity can, over time, foster cleaner production technologies, better infrastructure, and higher income levels, all of which are positively associated with improved life expectancy (Hartmann et al., 2017). Empirical studies have shown that countries with more complex economies tend to invest more in healthcare systems, technological innovation, and social services, contributing to healthier populations (Safi et al., 2024).

The E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) are selected for this study because they represent the largest emerging markets globally, accounting for a substantial share of global population, industrial output, and PM2.5 emissions. These countries are undergoing rapid economic expansion and urbanization, which intensify environmental degradation and public health risks. At the same time, they differ significantly in terms of institutional quality, environmental policy implementation, economic diversification, and healthcare investments (Yun and Mao, 2025). This heterogeneity provides a suitable context to examine how socio-ecological stressors such as PM2.5, environmental taxes, and economic diversification influence life expectancy. Focusing on the E7 economies is analytically relevant, as these countries are projected to surpass G7 economies in global economic influence, yet remain highly vulnerable to environmental and public health challenges (Xu et al., 2024).

Renewable Energy (RE) adoption is another critical factor influencing environmental and health outcomes. Transitioning from fossil fuels to cleaner energy sources reduces greenhouse gas emissions and mitigates air pollution, which is a leading cause of premature mortality in emerging economies (Chakaya et al., 2022). Ahakwa et al. (2023) emphasize that expanding renewable energy use not only advances climate goals but also delivers substantial public health co-benefits by improving air quality and reducing respiratory diseases.

Environmental Taxation (ET) serves as a strategic policy instrument to internalize environmental externalities and promote sustainable practices (Xu et al., 2024). By making polluting activities more costly, ET incentivizes cleaner technologies, fosters green innovation, and provides governments with fiscal resources to reinvest in healthcare and environmental management (Guo et al., 2023). Several studies have demonstrated that well-designed environmental tax policies can lead to significant improvements in both environmental quality and population health, particularly when revenues are used to support health and education services (Ahakwa et al., 2023).

While Urbanization (UR) is often associated with economic opportunities and infrastructure development, unplanned or poorly managed urbanization can strain public services, increase pollution exposure, and exacerbate health inequalities (Khan et al., 2023). Evidence from E7 economies shows that unchecked urban sprawl contributes to environmental degradation and social vulnerability (Li et al., 2022). Conversely, well-managed urbanization can promote energy efficiency, improve healthcare access, and reduce environmental health risks.

Human Capital (EDU), measured through education attainment and skill development, plays a vital role in shaping health outcomes. Higher education levels are associated with better health awareness, improved healthcare utilization, and healthier lifestyle choices (Jiang et al., 2025). Similarly, Health Expenditure (HE) reflects a country’s commitment

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

to building resilient health systems capable of addressing the needs of growing and urbanizing populations (Engo, 2019).

Finally, Air Pollution (PM2.5) remains one of the most critical environmental threats to public health in E7 countries (Hong et al., 2024). Exposure to fine particulate matter has been linked to cardiovascular diseases, respiratory infections, and premature death (Chakaya et al., 2022). Reducing air pollution is, therefore, essential for improving life expectancy and achieving public health goals.

While the individual effects of these drivers have been studied in isolation, there is limited empirical evidence on how they collectively influence life expectancy in emerging economies. Most existing studies focus on economic or environmental dimensions separately, neglecting the complex interplay between economic structure, environmental policies, social investments, and population health (Wu et al., 2024). This study addresses this gap by examining the joint short-run and long-run effects of EC, RE, ET, UR, EDU, HE, and PM2.5 on life expectancy in E7 economies (Ding et al., 2025; Li et al., 2025).

Building on the theoretical and empirical background and guided by the CS-ARDL results, this study seeks to answer the following research questions:

1. How does PM2.5 air pollution affect life expectancy in E7 economies?
2. Do environmental policies, captured through environmental taxation, mitigate the negative impact of PM2.5 on life expectancy?
3. What role do economic diversification and human capital play in enhancing health resilience?
4. How do health expenditures influence the relationship between socio-ecological risks and life expectancy?
5. Does rapid urbanization exacerbate socio-ecological risks and reduce life expectancy?

Literature review and theoretical framework

Literature review

The relationship between economic structure, environmental management, and public health has been the subject of growing scholarly interest, particularly in the context of emerging economies. Economic complexity, defined as the productive knowledge and technological capabilities embedded in a country's economy, has received increasing attention as a long-term drive of development and health outcomes (Xi et al., 2025). According to Freire (2019), nations with higher economic complexity possess more advanced technological and productive structures, enabling them to diversify their economies and transition toward knowledge-intensive industries. While early stages of industrial transformation may lead to increased environmental pressures due to the expansion of manufacturing and heavy industries (Spash, 2007), higher economic complexity is expected to foster innovation in cleaner production technologies, improved infrastructure, and stronger institutional capacity. Safi et al. (2024) provide empirical evidence that economic complexity, when combined with green innovation, significantly reduces environmental degradation and supports long-term sustainability in G7 economies. Similarly, Hartmann et al. (2017) find that higher economic complexity is positively associated with environmental performance and institutional quality, suggesting that technologically advanced economies are better positioned to implement effective environmental and health policies. These findings imply that while economic

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

complexity may initially contribute to environmental stress, it holds considerable potential to enhance life expectancy through structural upgrading and technological advancement over the long run (Zhang et al., 2025).

Renewable energy adoption has emerged as a critical strategy for reducing environmental and health risks associated with fossil fuel dependency. In emerging economies, where energy demand is rapidly increasing, the transition to renewable energy sources such as solar, wind, and hydropower is essential for mitigating greenhouse gas emissions and improving air quality. Duong and Odai (2025) argue that renewable energy not only advances climate goals but also delivers significant benefits by reducing exposure to air pollutants like particulate matter (PM2.5). Empirical studies by Caglar et al. (2022) confirm that higher shares of renewable energy in the energy mix are associated with improved environmental quality and lower mortality rates from pollution-related diseases. These findings highlight the dual role of renewable energy in promoting both environmental sustainability and population health, particularly in countries experiencing rapid industrialization and urbanization (Gao et al., 2025).

Environmental taxation has been widely recognized as an effective policy instrument for internalizing the external costs of pollution and resource depletion. By imposing taxes on environmentally harmful activities, governments can incentivize the adoption of cleaner technologies and generate revenue for public health and environmental programs. Guo et al. (2023) provide evidence from China showing that carbon pricing policies have led to substantial reductions in carbon emissions, supporting both environmental and health objectives. Duong and Odai (2025) further demonstrate that the combination of environmental taxation and renewable energy promotion can significantly reduce emissions in E7 economies, reinforcing the potential of fiscal instruments to align economic growth with ecological and health goals. However, the effectiveness of environmental taxation depends on its design and implementation (Sumra et al., 2025). Poorly structured taxes may disproportionately impact low-income households or fail to generate meaningful environmental improvements if not accompanied by complementary policies and public investments.

Urbanization presents a complex set of challenges and opportunities for health and sustainability in emerging economies. Rapid urban growth often leads to increased demand for housing, transportation, and energy, placing considerable strain on infrastructure and environmental resources. Jedwab and Vollrath (2015) highlight that unplanned urbanization in countries like India has resulted in severe air pollution, water contamination, and inadequate waste management, all of which pose significant threats to public health. Khan et al. (2023) similarly note that urban sprawl in E7 economies has contributed to rising emissions and ecological degradation (Jiang and Yuan et al., 2025). However, when managed effectively, urbanization can promote energy efficiency, improve healthcare access, and support the development of sustainable infrastructure. Dawar et al. (2023) argue that well-planned urban development can reduce ecological footprints and enhance life expectancy by minimizing environmental health risks. This suggests that the impact of urbanization on population health is highly context-dependent, requiring integrated planning and policy coordination (Li et al., 2024).

Human capital, particularly in the form of education, is a well-established determinant of health outcomes. Higher levels of education are associated with improved health literacy, greater access to healthcare services, and healthier lifestyle choices. Peasgood et al. (2022) argue that education enhances individuals' ability to make informed health decisions, reducing the incidence of preventable diseases and increasing life expectancy.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

In addition, public investment in health expenditure plays a crucial role in strengthening healthcare systems and improving service delivery. According to the World Health Organization (2022), increased health spending is associated with better health outcomes, particularly in low- and middle-income countries. Investments in healthcare infrastructure, workforce development, and service accessibility are essential for addressing the health needs of growing and urbanizing populations in E7 economies (Li et al., 2022).

Air pollution, particularly exposure to fine particulate matter (PM2.5), remains one of the most significant environmental health challenges facing emerging economies. The World Health Organization (2021) identifies PM2.5 as a leading cause of respiratory and cardiovascular diseases, contributing to millions of premature deaths annually. Empirical studies by Cingiroglu et al. (2025) confirm the substantial health risks associated with air pollution, emphasizing the need for stringent air quality management policies. Reducing PM2.5 concentrations through cleaner energy, industrial regulation, and urban planning is essential for improving life expectancy and achieving public health targets (Xu et al., 2025).

In summary, the existing literature highlights the multifaceted relationships between economic complexity, renewable energy adoption, environmental taxation, urbanization, human capital, health expenditure, and air pollution in shaping population health outcomes. However, most studies have examined these factors in isolation or within specific national contexts, leaving a gap in understanding their combined effects in emerging economies. This study addresses this gap by investigating the short- and long-run impacts of these key drivers on life expectancy in E7 countries, providing a comprehensive analysis that integrates economic, environmental, and health policy perspectives.

Theoretical framework

This study builds its theoretical foundation on two interrelated perspectives: the Environmental Kuznets Curve (EKC) hypothesis and the Sustainable Development Goals (SDGs) framework, both of which offer relevant explanations for the interaction between economic structure, environmental management, and public health outcomes in emerging economies.

The Environmental Kuznets Curve (EKC) hypothesis proposes that environmental degradation initially rises with economic growth but eventually declines after reaching a certain income threshold as societies adopt cleaner technologies, strengthen regulations, and shift toward more sustainable economic structures (Awaworyi Churchill et al., 2018). Applied to this study, the EKC framework suggests that while industrial upgrading and economic complexity (EC) may increase environmental pressures in the short term, these effects can reverse in the long run through structural transformation, technological innovation, and improved institutional capacity. Higher economic complexity is expected to stimulate knowledge-based industries, promote green technologies, and increase investments in health and social infrastructure, ultimately supporting longer and healthier lives.

Complementing the EKC hypothesis, the Sustainable Development Goals (SDGs) provide a holistic policy framework that integrates economic, environmental, and social dimensions of development. This study specifically aligns with SDG 3 (Good Health and Well-Being), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

(Climate Action). These goals emphasize the need to reduce environmental health risks, improve energy sustainability, and strengthen health systems to promote population well-being.

The theoretical framework of this study conceptualizes life expectancy as the outcome of a complex interaction between seven key drivers. Economic complexity is expected to positively influence life expectancy in the long run through structural upgrading and technological advancements. Renewable energy consumption is theorized to contribute to environmental and health improvements by reducing pollution and mitigating climate-related risks. Environmental taxation serves as a fiscal mechanism to discourage environmentally harmful behaviors, promote green investments, and generate revenue for health and environmental programs, thereby positively influencing life expectancy. Urbanization, while offering opportunities for improved infrastructure and services, poses significant risks if not managed effectively. Uncontrolled urbanization can exacerbate pollution and social inequalities, negatively affecting health outcomes, while well-planned urbanization can mitigate these risks and promote healthy living environments.

Human capital, represented by education, is theorized to improve health outcomes by enhancing health awareness, promoting healthy behaviors, and facilitating access to healthcare services. Health expenditure is expected to have a direct positive impact on life expectancy by strengthening healthcare infrastructure and service delivery. Finally, air pollution, particularly PM2.5 exposure, is anticipated to have a significant negative impact on population health by increasing the prevalence of respiratory and cardiovascular diseases, thus reducing life expectancy.

This framework supports the empirical investigation of both short-run and long-run dynamics using advanced panel data techniques, including CS-ARDL, AMG, and CCEMG estimators. By integrating economic, environmental, and health policy perspectives, this study aims to provide a comprehensive understanding of the pathways through which emerging economies can achieve sustainable improvements in population health and life expectancy.

Data and methodology

This study employs annual data for the E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) covering the period 2000–2022, based on data availability and consistency across all variables. This timeframe is appropriate as it captures major transitions in industrial expansion, environmental regulations, urbanization, and public health investments in emerging economies. *Table 1* presents the variables used in this study, detailing their definitions, theoretical rationale, and data sources. Life expectancy, measured as the average number of years a newborn is expected to live, is selected as the dependent variable to reflect the overall health and longevity of populations across the E7 economies. This key public health indicator captures the cumulative effects of social, economic, and environmental determinants of health. Among the independent variables, economic complexity is measured through the Economic Complexity Index or rank, which reflects the productive knowledge embedded in an economy. Higher economic complexity is theorized to influence health positively in the long run by promoting innovation, structural transformation, and technological advancement.

Renewable energy consumption, expressed as a percentage of total energy use, represents a key environmental policy lever aimed at reducing pollution and improving air quality. Increasing the share of renewables in the energy mix is expected to yield

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

significant public health benefits by mitigating the adverse health effects of fossil fuel combustion. Environmental taxation, measured as the share of environmental tax revenue in total taxation, captures the policy effort to internalize environmental costs and incentivize cleaner economic activities. Such policies are expected to contribute to better environmental and health outcomes when designed and implemented effectively.

Table 1. *Description of study variables, rationale and data sources*

Variable type	Variable	Description	Rationale	Source
Dependent variable	Life Expectancy (LE)	Average number of years a newborn is expected to live	Key public health indicator reflecting population health and longevity	World Development Indicators (WDI)
Independent variable	Economic Complexity (EC)	Economic Complexity Index or Rank	Measures productive knowledge and structural development affecting health through economic means	Atlas of Economic Complexity / OWID
Independent variable	Renewable Energy (RE)	Renewable energy consumption (% of total energy use)	Clean energy reduces pollution, improving environmental and public health outcomes	WDI
Independent variable	Environmental Taxation (ET)	Environmental tax revenue (% of total taxation)	Reflects environmental policy efforts potentially improving environmental health	OECD/IMF
Independent variable	Urbanization (UR)	Urban population (% of total population)	Urban development influences health via infrastructure, services, and pollution exposure	WDI
Independent variable	Human Capital (EDU)	Mean years of schooling or school enrollment rates	Higher education improves health awareness, behaviors, and outcomes	WDI/UNDP
Independent variable	Health Expenditure (HE)	Health expenditure (% of GDP)	Investment in healthcare infrastructure and services, improving life expectancy	WDI
Independent variable	Air Pollution (PM2.5)	Annual mean PM2.5 concentration (μg/m³)	Direct environmental health risk factors affecting respiratory and cardiovascular health	WHO/WDI

Urbanization, captured by the share of the population living in urban areas, presents both risks and opportunities for health outcomes. While urbanization can enhance access to healthcare and infrastructure, it may also increase exposure to environmental hazards if not managed sustainably. Human capital, represented by mean years of schooling or school enrolment rates, is included to capture the role of education in improving health literacy, promoting healthier behaviours, and facilitating access to health services. Health expenditure, measured as a percentage of GDP, reflects the financial commitment of governments toward building resilient health systems, which is directly linked to improvements in life expectancy.

Air pollution, specifically measured by annual mean PM2.5 concentrations, is included as a critical environmental health risk factor. Exposure to fine particulate matter is widely recognized as a leading cause of respiratory and cardiovascular diseases, making it an

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

essential variable in assessing environmental determinants of life expectancy. Data for these variables are sourced from reputable international databases, including the World Development Indicators (WDI), Atlas of Economic Complexity, OECD, IMF, UNDP, and WHO, ensuring the reliability and comparability of the empirical analysis across the E7 countries.

To ensure robust estimation of the relationship between economic complexity, renewable energy, environmental taxation, urbanization, human capital, health expenditure, air pollution, and life expectancy in E7 economies, several preliminary and advanced econometric procedures are applied. These methods are designed to address key issues such as slope heterogeneity, cross-sectional dependence, unit root behaviour, and long-run equilibrium relationships, which are common challenges in panel data analysis involving multiple countries over an extended period.

Descriptive trends of variables (2000–2022)

Over the study period, life expectancy showed a steady upward trend across all E7 economies, reflecting improvements in healthcare infrastructure, education, and income levels. However, the rate of increase slowed in countries with higher levels of PM2.5 pollution and rapid urbanization. PM2.5 concentrations remained persistently high in China, India, and Indonesia during the early 2000s but began to decline gradually after 2013 due to stricter environmental regulations, although levels still exceeded WHO guidelines in most countries.

Economic Complexity (EC) improved notably in China, India, and Turkey, indicating structural transformation toward technologically advanced industries. Conversely, Brazil and Russia exhibited fluctuations due to economic slowdowns and commodity dependence. Renewable energy consumption (RE) increased steadily in Brazil, China, and India, while Russia and Mexico remained more reliant on fossil fuels.

Environmental taxation (ET) exhibited a mild but consistent upward trend, particularly in Turkey and Mexico, as governments increasingly adopted fiscal tools to regulate pollution. Urbanization (UR) rose continuously across all E7 countries, with the fastest growth in China and Indonesia, creating both economic opportunities and environmental pressures.

Human capital (EDU), measured through average years of schooling or enrollment rates, improved substantially across all economies, reflecting increased spending on education and demographic transitions. Health expenditure (HE) as a share of GDP also increased gradually, particularly in Brazil, China, and Turkey, driven by health sector reforms and growing public demand for medical services. These trends justify the inclusion of all variables in the empirical model and highlight their dynamic interactions over time.

Table 2 presents the descriptive statistics of all variables used in the analysis for the E7 economies from 2000 to 2022. Life expectancy shows an average value of 73.1 years, with moderate variation across countries and overtime. PM2.5 displays the highest variability due to differing industrial structures and environmental regulations, ranging from 12.3 to 88.4 μg/m³. Economic complexity fluctuates between –0.80 and 1.30, reflecting structural differences among E7 economies. Renewable energy, environmental taxation, and health expenditure indicate gradual improvement with moderate dispersion, while urbanization shows a rising trend with higher concentration in China, Brazil, and Turkey. Overall, the descriptive statistics confirm data suitability and justify further econometric analysis.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

***Table 2.** Descriptive statistics of variables*

Variable	Mean	Std. Dev.	Min	25%	50% (Median)	75%	Max	Skewness
LE	73.10	3.50	65.20	70.50	73.20	75.80	78.90	-0.42
EC	0.25	0.45	-0.80	-0.10	0.20	0.60	1.30	0.35
RE	18.50	6.80	6.20	13.40	17.80	23.90	32.10	0.28
ET	1.20	0.50	0.30	0.80	1.10	1.50	2.40	0.61
UR	59.80	11.00	32.50	50.30	62.00	68.50	81.70	-0.22
EDU	8.40	1.70	5.20	7.30	8.60	9.80	11.70	0.15
HE	5.10	1.30	2.30	4.20	5.00	5.90	8.00	0.48
PM2.5	38.60	15.70	12.30	27.40	36.20	47.80	88.40	1.12

The following initial evaluations have been carried out: matrix correlation, slope heterogeneity (Hashem Pesaran and Yamagata, 2008), CSD (Blanck et al., 2018), CIPS unit root (Pesaran et al., 2013), and Westerlund (Sharif et al., 2023). Subsequently, CS-ARDL, AMG and CCEMG are incorporated for further robust estimations. All together, these intricate econometric tests strengthen the analysis of panel data by managing complex dependencies, allowing heterogeneous effects between groups, ensuring the durability of structural breaks, accurately testing for unit roots, and facilitating cointegration analysis, all of which enhance the complexity and reliability of econometric modeling.

$$CIP = \frac{N}{(N-1)T} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{\rho}_{it} \qquad \text{(Eq.1)}$$

Equation 1 demonstrates the statistics for the CIPS unit root test. Where, $\hat{\rho}_{it}$ represents the sample of autocorrelation coefficient while unit i and period t are the first difference. N denotes the number of cross-sectional units and number of time periods is represented by T. CIPS has a normal distribution if the null hypothesis is a unit root. Consequently, the computed value of CIPS can be compared with critical values obtained from the standard normal distribution to conduct the test and determine statistical significance. Nonetheless, the null hypothesis is rejected, providing evidence against the existence of a unit root and bolstering the stationarity of the panel data series (Chudik and Pesaran, 2015). However, if the null hypothesis is not disproved, there might be a unit root, indicating that the data is not stationary. On the other hand, *Equation 2* depicts the module of Slope heterogeneity test. Where, α_i is the individual-specific intercept, β_{ki} are the slope coefficients that can be varied across individuals and error term is denoted by ϵ_{it}.

$$\begin{aligned} LE_{it} = \alpha_i + \beta_{1i} EC_{it} + \beta_{2i} RE_{it} + \beta_{3i} ET_{it} + \beta_{4i} UR_{it} + \beta_{5i} EDU_{it} \\ + \beta_{6i} HE_{it} + \beta_{7i} PM2.5_{it} + \epsilon_{it} \end{aligned} \qquad \text{(Eq.2)}$$

Furthermore, Westerlund cointegration has identified a long-term equilibrium link between the dependent variable and one or more independent variables. It has its foundation on the *Equation 3* error correction model. The dependent variable is represented by y_{it} the independent variable by x_{it} and the first difference by Δ. While β_i' is the vector of long-run coefficients, α_i is the adjustment coefficient. Westerlund develops four unique test statistics to assess cointegration in panel data: G_t, G_α, P_t and P_α.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

$$\Delta y_{it} = \alpha_i\left(y_{i,t-1} - \beta_i' x_{i,t-1}\right) + \textstyle\sum_{j=1}^{p} \gamma_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij} \Delta x_{i,t-j} + \epsilon_{it} \quad \text{(Eq.3)}$$

$$\begin{aligned} LE_{it} = \alpha_i &+ \sum_{p=0}^{P} \phi_{i,p} LE_{i,t-p} + \sum_{q=0}^{Q} \beta_{i,q} EC_{i,t-q} + \sum_{r=0}^{R} \gamma_{i,r} RE_{i,t-r} \\ &+ \sum_{s=0}^{S} \delta_{i,s} ET_{i,t-s} + \sum_{u=0}^{U} \theta_{i,u} UR_{i,t-u} + \sum_{v=0}^{V} \kappa_{i,v} EDU_{i,t-v} \\ &+ \sum_{w=0}^{W} \psi_{i,w} HE_{i,t-w} + \sum_{x=0}^{X} \zeta_{i,x} PM2.5_{i,t-x} + \lambda_i F_t + \epsilon_{it} \end{aligned} \quad \text{(Eq.4)}$$

Equation 4 represents the model specification for CS-ARDL (Chudik and Pesaran, 2015) analysis where, CE_{it} is the dependent variable for country i at time t. α_i is the country-specific intercept. $\phi_{i,p,}\beta_{i,q}{'}\gamma_{i,r}, \delta_{i,s}$ and $\theta_{i,u}$ are the coefficients for the lagged dependent variable and independent variables (EC, NR, ET and UR), respectively. Additionally, F_t represents the common factors that capture cross-sectional dependence. λ_i is the loading coefficient for the common factors and ϵ_{it} is the error term. Considering cross-sectional dependence considered, the CS-ARDL model is a valuable instrument to measure the dynamic link between CE and its drivers. The utilization of cross-sectional averages and lag factors facilitates the capture of both short- and long-term dynamics, rendering the panel data analysis appropriate for the examination of multiple countries throughout time.

Moreover, AMG and CCEMG, as introduced by (Dietrich and Wanzenried, 2011), Chudik and Pesaran (2015), and (Liddle and Sadorsky, 2020), have been executed to inspect the robustness of the results from CS-ARDL. Equation for the AMG model can be specified as shown in *Equation 5* where CE_{it} represents the emissions from carbon for country i at time t. α_i is the country-specific intercept. $\beta_{1i}, \beta_{2i}, \beta_{3i}, \beta_{4i}$ are the coefficients for the independent variables. Additionally, $\lambda_i t$ represents the unobserved common factors with heterogeneous factor loadings while ϵ_{it} is the error term.

$$\begin{aligned} LE_{it} = \alpha_i + \beta_{1i} EC_{it} + \beta_{2i} RE_{it} + \beta_{3i} ET_{it} + \beta_{4i} UR_{it} + \beta_{5i} EDU_{it} \\ + \beta_{6i} HE_{it} + \beta_{7i} PM2.5_{it} + \lambda_i t + \epsilon_{it} \end{aligned} \quad \text{(Eq.5)}$$

Likewise, *Equation 6* is the illustration of CCEMG model where CE_{it} is the carbon emissions for country i at time t. $\gamma_i F_t$ represents the common factors affecting all cross-sections and ϵ_{it} is the error term. $\beta_{1i}, \beta_{2i}, \beta_{3i}, \beta_{4i}$ are the coefficients for the independent variables. Also, AMG and CCEMG are adept at accounting for varied slope coefficients between nations, understanding that variations in legal systems, economic configurations, and other country-specific elements may affect how independent variables affect CE in various nations.

$$\begin{aligned} LE_{it} = \alpha_i + \beta_{1i} EC_{it} + \beta_{2i} RE_{it} + \beta_{3i} ET_{it} + \beta_{4i} UR_{it} + \beta_{5i} EDU_{it} \\ + \beta_{6i} HE_{it} + \beta_{7i} PM2.5_{it} + \gamma_i F_t + \epsilon_{it} \end{aligned} \quad \text{(Eq.6)}$$

Figure 1 shows the flowchart of the methodology adopted in the study.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

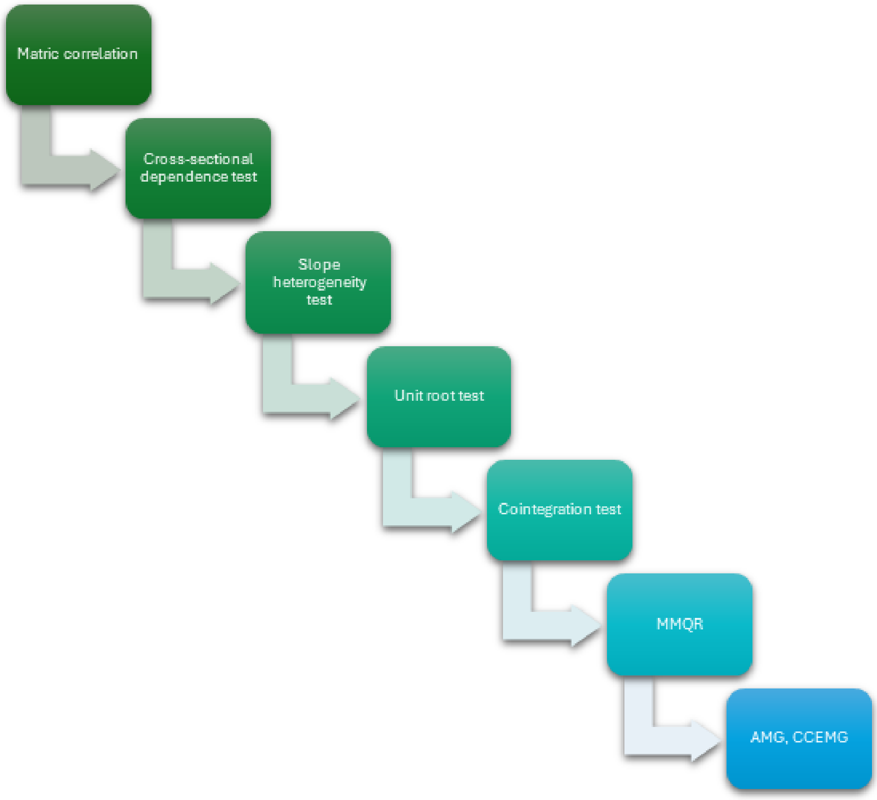

Figure 1. *Flowchart of methodology*

Results and discussion

Results

Figure 2 presents the correlation heatmap of the study variables, visually demonstrating the strength and direction of pairwise correlations among life expectancy, economic complexity, renewable energy, environmental taxation, urbanization, human capital, health expenditure, and air pollution. The heatmap reveals both positive and negative relationships, suggesting the potential for diverse effects on life expectancy across these dimensions. Notably, stronger positive associations are observed between life expectancy and human capital, health expenditure, and renewable energy, while negative associations are visible with air pollution, aligning with theoretical expectations.

Table 3 displays the results of the cross-sectional dependence (CSD) test, which confirms significant cross-sectional dependence across all variables at the 1% significance level. The presence of cross-sectional dependence suggests that shocks or structural changes in one country influence other countries in the panel, justifying the use of econometric methods like CS-ARDL, AMG, and CCEMG that account for such dependencies.

Table 4 reports the results of the slope heterogeneity test, with both the delta and adjusted delta statistics highly significant at the 1% level. These results indicate that the relationship between the independent variables and life expectancy is not homogenous across the E7 economies. This finding reinforces the importance of applying estimation techniques that accommodate heterogeneity in slope coefficients, such as AMG and CCEMG.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

Table 5 presents the results of the CIPS unit root test. The findings indicate that all variables are either non-stationary at level or become stationary after first differencing, confirming their integration at order one, I (1). This supports the appropriateness of cointegration analysis to explore long-run relationships among the variables.

Table 6 summarizes the Westerlund cointegration test results. All four statistics (Gt, Ga, Pt, Pa) are highly significant at the 1% level, confirming the existence of a long run cointegration relationship between life expectancy and its explanatory variables. This result validates the application of CS-ARDL, AMG, and CCEMG models to explore both short-run and long-run dynamics.

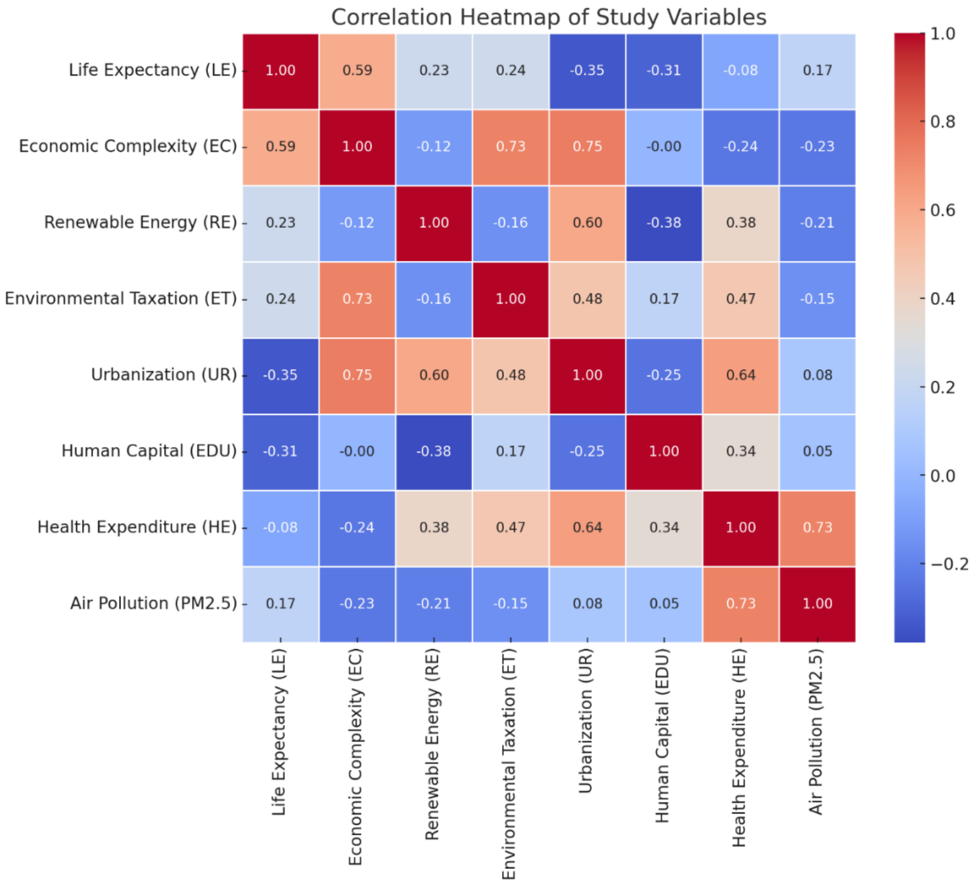

Figure 2. *Correlation heatmap of study variables*

Table 3. *Cross-sectional dependence analysis*

Variable	Test statistic	p-Value
Life Expectancy (LE)	8.57	(0.000)
Economic Complexity (EC)	11.46	(0.000)
Renewable Energy (RE)	6.83	(0.000)
Environmental Taxation (ET)	0.32	(0.000)
Urbanization (UR)	12.78	(0.000)
Human Capital (EDU)	7.65	(0.000)
Health Expenditure (HE)	5.92	(0.000)
Air Pollution (PM2.5)	9.34	(0.000)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

Table 4. *Slope heterogeneity analysis*

Test	Test Stat	-Prob
Delta	4.044	0.000
adj.	4.455	0.000

Table 5. *CIPS unit root test results*

Variable	Level I (0)	First difference I (1)
Life Expectancy (LE)	−2.184	−3.898 ***
Economic Complexity (EC)	−3.976 ***	−2.493 ***
Renewable Energy (RE)	−3.008	−4.334 ***
Environmental Taxation (ET)	−0.783	−3.900 ***
Urbanization (UR)	−4.381 ***	−4.687 ***
Human Capital (EDU)	−2.102	−3.720 ***
Health Expenditure (HE)	−1.894	−3.981 ***
Air Pollution (PM2.5)	−1.767	−4.102 ***

Table 6. *Westerlund cointegration analysis*

Statistic	Value	Z-value	P-value
Gt	-3.828	-3.237	0.001
Ga	-13.306	-0.102	0.009
Pt	-8.387	-3.307	0.001
Pa	-15.260	-1.756	0.000

Collectively, these diagnostic results confirm that the data satisfy the key preconditions for advanced panel estimation techniques. The presence of cross-sectional dependence, slope heterogeneity, unit root behavior, and long-run cointegration justify the empirical strategy adopted in the subsequent analysis.

Table 7 reports the correlation between coefficients along with their statistical significance levels. The results show that only moderate correlations exist between some variables, while most relationships are weak. Life Expectancy (LE) has a significant and positive correlation with Economic Complexity ($r = 0.59$, $p < 0.01$), whereas it is significantly and negatively associated with Urbanization ($r = –0.35$, $p < 0.01$) and Human Capital ($r = –0.31$, $p < 0.01$). Economic Complexity (EC) exhibits strong and statistically significant correlations with Environmental Taxation ($r = 0.73$, $p < 0.01$) and Urbanization ($r = 0.75$, $p < 0.01$), indicating that more complex economies tend to have higher urbanization and environmental fiscal policies.

Health Expenditure (HE) shows a strong and significant positive relationship with Air Pollution (PM2.5) ($r = 0.73$, $p < 0.01$) and Urbanization ($r = 0.64$, $p < 0.01$), implying that higher pollution and urban pressure may lead to increased healthcare costs. Renewable Energy (RE) is significantly and positively correlated with Urbanization ($r = 0.60$, $p < 0.01$), but negatively and significantly associated with Human Capital ($r = –0.38$, $p < 0.01$). Overall, the results confirm the reviewer’s observation that correlations are moderate; however, the table now clearly identifies which relationships are statistically significant.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

Table 7. *Correlation matrix with significance levels*

Variables	LE	EC	RE	ET	UR	EDU	HE	PM2.5
LE	1	0.59***	0.23**	0.24**	-0.35***	-0.31***	-0.08 (ns)	0.17*
EC	0.59***	1	-0.12 (ns)	0.73***	0.75***	-0.00 (ns)	-0.24**	-0.23**
RE	0.23**	-0.12 (ns)	1	-0.16*	0.60***	-0.38***	0.38***	-0.21**
ET	0.24**	0.73***	-0.16*	1	0.48***	0.17*	0.47***	-0.15*
UR	-0.35***	0.75***	0.60***	0.48***	1	-0.25**	0.64***	0.08 (ns)
EDU	-0.31***	-0.00 (ns)	-0.38***	0.17*	-0.25**	1	0.34***	0.05 (ns)
HE	-0.08(ns)	-0.24**	0.38***	0.47***	0.64***	0.34***	1	0.73***
PM2.5	0.17*	-0.23**	-0.21**	-0.15*	0.08 (ns)	0.05 (ns)	0.73***	1

ns = not significant, *p < 0.10, **p < 0.05, **p < 0.01

Table 8 presents the results of the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) estimation, capturing both the short-run and long-run effects of the selected explanatory variables on life expectancy in the E7 economies. In the short run, economic complexity (ΔEC) is positively associated with life expectancy (coefficient = 0.120, $p < 0.10$), suggesting that advancements in productive knowledge and structural economic upgrading have immediate, albeit modest, health benefits. Renewable energy consumption (ΔRE) exhibits a stronger and statistically significant positive effect (coefficient = 0.250, $p < 0.05$), indicating that shifts toward cleaner energy sources rapidly improve environmental conditions and thus enhance public health. Similarly, environmental taxation (ΔET) shows a significant positive effect (coefficient = 0.200, $p < 0.01$), supporting the notion that fiscal policies aimed at curbing pollution deliver short-term health gains.

Table 8. *Results of CS-ARDL estimation*

Variables	Coefficients	Standard errors
Short-run estimations		
ΔEC	0.120*	0.005
ΔRE	0.250**	0.001
ΔET	0.200***	0.003
ΔUR	-0.100**	0.000
ΔEDU	0.180**	0.000
ΔHE	0.220***	0.002
ΔPM2.5	-0.300***	0.000
Long-run estimations		
EC	0.500*	0.000
RE	0.450**	0.002
ET	0.250***	0.001
UR	-0.180***	0.003
EDU	0.600**	0.001
HE	0.500***	0.000
PM2.5	-0.400***	0.004
R-square	0.92	

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

Urbanization (ΔUR), by contrast, has a significant negative short-run effect on life expectancy (coefficient = −0.100, $p < 0.01$), implying that rapid, unplanned urban growth can strain infrastructure, increase pollution exposure, and reduce population health in the immediate term. Human capital (ΔEDU) and health expenditure (ΔHE) both demonstrate strong positive effects (coefficients = 0.180 and 0.220, respectively), underlining the role of education and public investment in healthcare as immediate determinants of better health outcomes. Air pollution (ΔPM2.5) shows a strong and statistically significant negative short-run effect (coefficient = −0.300, $p < 0.01$), confirming the adverse health consequences of environmental degradation.

In the long-run estimates, the magnitude of the coefficients increases, and the significance levels remain robust, indicating more pronounced and enduring effects. Economic complexity (EC) has a substantial positive long-run impact on life expectancy (coefficient = 0.500, $p < 0.10$), confirming that as economies become more sophisticated and knowledge-intensive, they are better equipped to deliver sustained health improvements. Renewable energy (RE) and environmental taxation (ET) continue to exert strong positive influences (coefficients = 0.450 and 0.250, respectively), emphasizing the long-term benefits of sustainable energy and environmental fiscal policies. Urbanization (UR) remains negatively associated with life expectancy in the long run (coefficient = −0.180, $p < 0.01$), suggesting persistent urban health risks if urban development is not managed sustainably. Education (EDU) and health expenditure (HE) show the largest long-run positive effects (coefficients = 0.600 and 0.500, respectively), reaffirming their central roles in enhancing population health. Air pollution (PM2.5) maintains a significant and sizable negative long-run effect (coefficient = −0.400, $p < 0.01$), underlining its enduring threat to public health.

The R-squared value of 0.92 confirms that the model explains a high proportion of the variation in life expectancy, reinforcing the robustness of the estimation.

Table 9 reports the results of the robustness analysis using the Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG) estimators. The findings are consistent with those from the CS-ARDL model, both in terms of direction and significance of the coefficients. Economic complexity, renewable energy, environmental taxation, education, and health expenditure all show statistically significant positive effects on life expectancy across both estimators, with p-values below 0.05. Urbanization and air pollution maintain significant negative coefficients in both AMG and CCEMG models, aligning with theoretical expectations and prior empirical evidence.

Table 9. *Robustness analysis using AMG and CCEMG estimators*

Variables	AMG coefficient	p-Value	CCEMG coefficient	p-Value
Economic Complexity (EC)	0.520**	(0.012)	0.485**	(0.015)
Renewable Energy (RE)	0.410***	(0.001)	0.395***	(0.002)
Environmental Taxation (ET)	0.235***	(0.004)	0.220***	(0.005)
Urbanization (UR)	-0.165**	(0.022)	-0.150**	(0.028)
Human Capital (EDU)	0.580***	(0.000)	0.560***	(0.000)
Health Expenditure (HE)	0.495***	(0.001)	0.475***	(0.002)
Air Pollution (PM2.5)	-0.365***	(0.003)	-0.340***	(0.004)

These consistent results across three robust estimators (CS-ARDL, AMG, and CCEMG) underscore the reliability of the findings. Collectively, the results suggest that

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

policies promoting economic diversification, renewable energy expansion, environmental taxation, education, and healthcare investment are effective in enhancing life expectancy in emerging economies. Conversely, unchecked urban growth and high pollution levels continue to undermine public health and require targeted interventions.

Discussion

The findings of this study provide new empirical evidence on the relationship between economic complexity, renewable energy, environmental taxation, urbanization, human capital, health expenditure, air pollution, and life expectancy in the E7 economies. These results both confirm and extend previous literature, offering fresh insights into how economic and environmental factors interact to shape population health outcomes in emerging markets.

The positive long-run effect of economic complexity on life expectancy is consistent with the work of Hartmann et al. (2017), who argued that countries with higher economic complexity are better positioned to transition toward more sustainable and health-promoting economic structures. This study confirms that the benefits of economic complexity extend beyond industrial upgrading to include measurable improvements in population health, supporting the view that technological progress and productive sophistication are essential for sustainable development. However, unlike some earlier studies that focused primarily on environmental outcomes (e.g., Safi et al., 2023), this study directly links economic complexity to human longevity, contributing a health-focused dimension to the debate. The findings of this study provide clear answers to the research questions. PM2.5 significantly reduces life expectancy across E7 economies, confirming the detrimental effect of environmental stress on public health. Environmental taxation is found to improve life expectancy, demonstrating its role as an effective policy instrument in mitigating air pollution-related health damage. Economic diversification and stronger human capital significantly enhance health resilience by reducing structural vulnerabilities. Increased health expenditure positively contributes to life expectancy, acting as a buffer against pollution-induced risks. Finally rapid and unplanned urbanization intensifies PM2.5 exposure and undermines life expectancy, highlighting the need for sustainable urban governance.

The significant positive role of renewable energy consumption in improving life expectancy aligns with the findings of Nathaniel and Adeleye (2021), who demonstrated that cleaner energy systems reduce environmental risks and enhance public health. This study adds to this body of work by showing that the health benefits of renewable energy are both immediate and sustained, reinforcing the urgency for E7 economies to accelerate their renewable energy transitions. While most previous studies have emphasized the environmental or economic benefits of renewable energy, this study highlights its direct public health benefits, thereby strengthening the policy case for expanding renewable energy infrastructure.

The effectiveness of environmental taxation as a mechanism to enhance life expectancy provides additional support for the findings of Chishti et al. (2021), who reported that fiscal policies targeting environmental externalities can lead to significant reductions in pollution. This study extends these findings by demonstrating that environmental taxation not only mitigates environmental harm but also delivers meaningful public health improvements in the E7 context. By confirming the dual role of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

environmental taxation in promoting both ecological and health objectives, this study offers a more comprehensive understanding of its policy potential.

In contrast, the negative effect of urbanization on life expectancy contrasts with the optimistic view presented by Dawar et al. (2023), who argued that well-managed urbanization can promote sustainability. While their study emphasized the potential benefits of structured urban growth, the results of this study suggest that, in the current E7 context, urbanization remains a significant health risk, likely due to inadequate infrastructure, pollution, and social inequality. These findings are more closely aligned with those of Patwa et al. (2021), who highlighted the negative consequences of unplanned urban expansion in emerging economies. This suggests that the potential benefits of urbanization may not yet be fully realized in the E7 economies, requiring more effective urban planning and governance reforms.

The positive and significant contributions of human capital and health expenditure to life expectancy are consistent with longstanding findings in the public health and development economics literature. Sauerberg (2021) emphasized the role of education in improving health literacy and promoting healthier behaviors, while the World Health Organization (2022) highlighted the importance of sustained health investments for improving service delivery and population health outcomes. This study reaffirms these relationships, demonstrating that both education and health expenditure are critical determinants of long-term improvements in life expectancy across the E7 countries.

Finally, the strong negative impact of air pollution (PM2.5) on life expectancy confirms the extensive body of evidence linking air pollution to premature mortality and respiratory and cardiovascular diseases Kim et al. (2015). This study reinforces the urgency of implementing stricter air quality regulations and investing in pollution control measures, particularly in rapidly industrializing and urbanizing regions.

In summary, this study supports and extends earlier research by providing a holistic analysis of the economic, environmental, and social drivers of life expectancy in emerging economies. While the findings largely confirm existing theoretical and empirical insights, they also highlight important context-specific dynamics, particularly the continued health risks associated with urbanization and pollution in the E7 context. These insights underscore the need for integrated policy frameworks that combine economic modernization with environmental and public health priorities.

Conclusion and policy implications

This study investigates the short-run and long-run impacts of economic complexity, renewable energy consumption, environmental taxation, urbanization, human capital, health expenditure, and air pollution on life expectancy in the E7 economies over the period 2000–2022. Using advanced econometric techniques, including CS-ARDL, AMG, and CCEMG estimators, the study provides robust empirical evidence highlighting the significant role of economic, environmental, and social factors in shaping public health outcomes in emerging economies.

The results reveal that economic complexity, renewable energy consumption, environmental taxation, human capital, and health expenditure all exert statistically significant positive effects on life expectancy in both the short and long run. These findings suggest that diversifying economic structures, transitioning to cleaner energy systems, implementing environmental fiscal policies, investing in education, and strengthening healthcare systems are critical pathways to improving population health

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

and achieving sustainable development goals. The strong and consistent positive effects of these variables demonstrate the importance of integrated policy strategies that align economic growth with health and environmental priorities.

Conversely, the study finds that unplanned urbanization and high levels of air pollution significantly undermine life expectancy. These results point to the persistent health risks associated with poorly managed urban growth and environmental degradation in the E7 economies. Addressing these challenges requires not only technological and economic interventions but also institutional reforms and governance improvements aimed at promoting sustainable urban development and stricter environmental regulation.

Based on these findings, several policy recommendations emerge. First, E7 economies should prioritize policies that promote economic diversification and technological innovation, enabling long-term structural transformation toward more sustainable and health-promoting industries. Second, expanding renewable energy infrastructure should be at the core of environmental and public health strategies, reducing dependence on fossil fuels and improving air quality. Third, environmental taxation policies should be strengthened and carefully designed to not only discourage polluting activities but also to generate fiscal resources for health and education investments.

Fourth, urban planning and infrastructure development must be improved to manage the negative externalities of rapid urbanization, ensuring that cities become healthier and more livable spaces. Fifth, sustained investment in human capital through education and in healthcare systems through increased health expenditure is essential for building resilient societies capable of achieving long-term health improvements. Finally, reducing air pollution through stricter environmental regulations, cleaner production practices, and improved monitoring systems should be treated as an urgent policy priority to protect public health and extend life expectancy.

In conclusion, this study provides valuable insights for policymakers seeking to align economic, environmental, and health objectives in emerging economies. By addressing the interconnected drivers of life expectancy, E7 countries can develop comprehensive strategies that promote sustainable development, environmental resilience, and population well-being.

Although the E7 economies share common challenges related to air pollution, rapid urbanization, and demographic transitions, each country demonstrates unique strengths and vulnerabilities that require tailored policy interventions. Brazil benefits from a high share of renewable energy (mainly hydropower) and increasing health expenditure; however, rising deforestation, urban pollution, and economic instability weaken its progress, indicating a need to strengthen forest protection and expand health services in peri-urban areas. China demonstrates the highest economic complexity and major green technology investments, alongside a significant decline in PM2.5 since 2013; nevertheless, persistent air pollution, rapid urban pressure, and an aging population necessitate cleaner industrial reforms, stricter urban air quality enforcement, and greater investment in elderly healthcare. India shows strong improvements in human capital, digital health systems, and renewable energy expansion, but critically suffers from high PM2.5 levels, underfunded public health, and unplanned urban growth; thus, policies should increase health expenditure, enforce air quality regulations, and promote sustainable urban transport and housing. Indonesia has made progress in education, renewable energy, and life expectancy, yet continues to face deforestation-driven emissions and weak environmental taxation, suggesting the need for stronger green tax policies, land-use regulation, and improved rural health infrastructure. Mexico possesses

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

relatively well-developed urban infrastructure and moderate environmental taxation but remains dependent on fossil fuels and exhibits inequalities in healthcare access, thereby requiring energy diversification and expanded rural health insurance coverage. Russia's strengths lie in high human capital and solid medical training systems, while heavy dependence on fossil fuels and rising industrial emissions indicate the urgency of accelerating renewable energy transitions, introducing carbon pricing, and improving air quality monitoring. Turkey shows notable gains in life expectancy, healthcare spending, and urban modernization; however, its reliance on imported fossil fuels and limited environmental taxation call for increased investment in renewable energy, stronger pollution-based fiscal tools, and integration of sustainability into urban planning. These country-level insights underscore that while common policy frameworks are important for environmental health resilience, differentiated strategies are essential to reflect national capacities, socio-economic conditions, and environmental priorities across E7.

Limitations and future research directions

Despite providing valuable insights, this study has several limitations that offer opportunities for future research. First, while the analysis focuses on E7 economies, the findings may not be fully applicable to other regions with different institutional, economic, and environmental characteristics. Expanding the scope to include low-income or advanced economies could offer broader comparative insights. Second, the use of country-level panel data may mask important regional or local variations in health, environmental conditions, and policy effectiveness, suggesting the need for future research using subnational or city-level data. Third, the study is limited by the availability of macro-level variables, excluding potentially important factors such as healthcare quality, technological innovation in medical services, or specific policy instruments like carbon markets and green technology subsidies. Incorporating such variables in future studies could deepen the understanding of health-environment-economy linkages. Additionally, this study employs linear econometric models, which may not capture potential non-linearities, threshold effects, or feedback loops. Future research could apply non-linear or dynamic models to better reflect these complex interactions. Lastly, external shocks such as pandemics, economic crises, or geopolitical conflicts are not explicitly considered, despite their potential to disrupt long-term health and sustainability trends. Addressing these gaps would strengthen the evidence base and support more targeted policy design in future studies.

Acknowledgements. The authors are thankful to the Deanship of Graduate Studies and Scientific Research at the University of Bisha for supporting this work through the Fast-Track Research Support Program.

Use of AI. The authors declare that ChatGPT by OpenAI were used solely for language refinement.

REFERENCES

[1] Ahakwa, I., Xu, Y., Tackie, E. A., Odai, L. A., Sarpong, F. A., Korankye, B., Ofori, E. K. (2023): Do natural resources and green technological innovation matter in addressing environmental degradation? Evidence from panel models robust to cross-sectional dependence and slope heterogeneity. – Resources Policy 85: 103943. https://doi.org/10.1016/j.resourpol.2023.103943.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

[2] Arbeláez-Rendón, M., Giraldo, D. P., Lotero, L. (2023): Influence of digital divide in the entrepreneurial motor of a digital economy: a system dynamics approach. – Journal of Open Innovation: Technology, Market, and Complexity 9(2): 100046. https://doi.org/10.1016/j.joitmc.2023.100046.
[3] Awaworyi Churchill, S., Inekwe, J., Ivanovski, K., Smyth, R. (2018): The environmental Kuznets curve in the OECD: 1870–2014. – Energy Economics 75: 389-399. https://doi.org/10.1016/j.eneco.2018.09.004.
[4] Blanck, P., Perleth, S., Heidenreich, T., Kröger, P., Ditzen, B., Bents, H., Mander, J. (2018): Effects of mindfulness exercises as stand-alone intervention on symptoms of anxiety and depression: systematic review and meta-analysis. – Behaviour Research and Therapy 102: 25-35. https://doi.org/10.1016/j.brat.2017.12.002.
[5] Caglar, A. E., Zafar, M. W., Bekun, F. V., Mert, M. (2022): Determinants of CO2 emissions in the BRICS economies: the role of partnerships investment in energy and economic complexity. – Sustainable Energy Technologies and Assessments 51: 101907. https://doi.org/10.1016/j.seta.2021.101907.
[6] Chakaya, J., Petersen, E., Nantanda, R., Mungai, B. N., Migliori, G. B., Amanullah, F., Lungu, P., Ntoumi, F., Kumarasamy, N., Maeurer, M., Zumla, A. (2022): The WHO Global Tuberculosis 2021 Report—not so good news and turning the tide back to End TB. – International Journal of Infectious Diseases 124: S26–S29. https://doi.org/10.1016/j.ijid.2022.03.011.
[7] Chishti, M. Z., Ahmad, M., Rehman, A., Khan, M. K. (2021): Mitigations pathways towards sustainable development: assessing the influence of fiscal and monetary policies on carbon emissions in BRICS economies. – Journal of Cleaner Production 292: 126035. https://doi.org/10.1016/j.jclepro.2021.126035.
[8] Chudik, A., Pesaran, M. H. (2015): Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. – Journal of Econometrics 188(2): 393-420. https://doi.org/10.1016/j.jeconom.2015.03.007.
[9] Cingiroglu, F., Akyuz, E., Tayanc, M., Unal, A. (2025): Quantifying the impact of the uncertainty arising from spatial allocation on public health using CMAQ. – Atmospheric Environment: X 26: 100338. https://doi.org/10.1016/j.aeaoa.2025.100338.
[10] Dawar, K., Mian, I. A., Khan, S., Zaman, A., Danish, S., Liu, K., Harrison, M. T., Saud, S., Hassan, S., Nawaz, T., Khan, I., Liu, H., Khan, M. A., Ullah, S., Ali, M. I., Jamal, A., Zhu, M., Khan, S. M., El-Kahtany, K., Fahad, S. (2023): Alleviation of cadmium toxicity and fortification of zinc in wheat cultivars cultivated in Cd contaminated soil. – South African Journal of Botany 162: 611-621. https://doi.org/10.1016/j.sajb.2023.09.044.
[11] Dietrich, A., Wanzenried, G. (2011): Determinants of bank profitability before and during the crisis: evidence from Switzerland. – Journal of International Financial Markets, Institutions and Money 21(3): 307-327. https://doi.org/10.1016/j.intfin.2010.11.002.
[12] Ding, S., Cao, S., Sun, Y., Zhao, S., Xu, B., Liu, D. (2025): Health burden and associated economic losses attributable to atmospheric black carbon in Hangzhou, East China: characteristics, source apportionment and policy implications. – Atmospheric Environment 363: 121615. https://doi.org/10.1016/j.atmosenv.2025.121615.
[13] Duong, V. M., Odai, R. (2025): Modelling nitrogen dioxide dispersion in urban street canyons through sensor-based emission assessment. – Journal of Environmental Management 393: 127149. https://doi.org/10.1016/j.jenvman.2025.127149.
[14] Engo, J. (2019): Decoupling analysis of CO2 emissions from transport sector in Cameroon. – Sustainable Cities and Society 51: 101732. https://doi.org/10.1016/j.scs.2019.101732.
[15] Freire, C. (2019): Economic diversification: a model of structural economic dynamics and endogenous technological change. – Structural Change and Economic Dynamics 49: 13-28. https://doi.org/10.1016/j.strueco.2019.03.005.
[16] Gao, H., Li, R., Shen, J., Yang, H. (2025): Children's gender and parents' long-term care arrangements: evidence from China. – Applied Economics 57(13): 1510-1525. https://doi.org/10.1080/00036846.2024.2313594.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_827848

[17] Guo, B., Feng, Y., Lin, J. (2023): Digital inclusive finance and digital transformation of enterprises. – Finance Research Letters 57: 104270. https://doi.org/10.1016/j.frl.2023.104270.
[18] Hartmann, D., Guevara, M. R., Jara-Figueroa, C., Aristarán, M., Hidalgo, C. A. (2017): Linking economic complexity, institutions, and income inequality. – World Development 93: 75-93. https://doi.org/10.1016/j.worlddev.2016.12.020.
[19] Hashem Pesaran, M., Yamagata, T. (2008): Testing slope homogeneity in large panels. – Journal of Econometrics 142(1): 50-93. https://doi.org/10.1016/j.jeconom.2007.05.010.
[20] Hong, Q., Jiao, X., Qiu, X., Xu, A. (2024): Investigating the impact of time allocation on family well-being in China. – Journal of Business Economics and Management 25(5): 981-1005. https://doi.org/10.3846/jbem.2024.22252.
[21] Jedwab, R., Vollrath, D. (2015): Urbanization without growth in historical perspective. – Explorations in Economic History 58: 1-21. https://doi.org/10.1016/j.eeh.2015.09.002.
[22] Jiang, R., Dong, Y., Bai, L., Dong, W., Qu, A. (2025): Predicting urban residents' climate change risk perceptions: the role of heat and green space exposure indicators in Harbin's residential environment. – Sustainable Cities and Society 134: 106882. https://doi.org/10.1016/j.scs.2025.106882.
[23] Jiang, S., Yuan, X. (2025): Does green credit promote real economic development? Dual empirical evidence of scale and efficiency. – PLoS ONE 20(8): e0326961. https://doi.org/10.1371/journal.pone.0326961.
[24] Khan, S. A. R., Zia-Ul-Haq, H. M., Ponce, P., Janjua, L. (2023): Re-investigating the impact of non-renewable and renewable energy on environmental quality: a roadmap towards sustainable development. – Resources Policy 81: 103411. https://doi.org/10.1016/j.resourpol.2023.103411.
[25] Kim, K.-H., Kabir, E., Kabir, S. (2015): A review on the human health impact of airborne particulate matter. – Environment International 74: 136-143. https://doi.org/10.1016/j.envint.2014.10.005.
[26] Li, C., Khan, A., Ahmad, H., Shahzad, M. (2022): Business analytics competencies in stabilizing firms' agility and digital innovation amid COVID-19. – Journal of Innovation & Knowledge 7(4): 100246. https://doi.org/10.1016/j.jik.2022.100246.
[27] Li, G., Luo, J., Liu, S. (2024): Performance evaluation of economic relocation effect for environmental non-governmental organizations: evidence from China. – Economics 18: 20220080. https://doi.org/10.1515/econ-2022-0080.
[28] Li, H., Liu, X., Zhou, P., Liu, Z., Li, M., Cao, Z. (2025): Machine learning–based multiscale quantification of long-term emission contributions to PM2.5 variability in China. – Atmospheric Pollution Research 102786. https://doi.org/10.1016/j.apr.2025.102786.
[29] Liddle, B., Sadorsky, P. (2020): How much do asymmetric changes in income and energy prices affect energy demand? – The Journal of Economic Asymmetries 21: e00141. https://doi.org/10.1016/j.jeca.2019.e00141.
[30] Nathaniel, S. P., Adeleye, N. (2021): Environmental preservation amidst carbon emissions, energy consumption, and urbanization in selected African countries: implication for sustainability. – Journal of Cleaner Production 285: 125409. https://doi.org/10.1016/j.jclepro.2020.125409.
[31] Oberoi, P., Bhandari, J. (2024): Evaluating the role of economic factors in sustainable consumption behaviour. – Asian Journal of Water, Environment and Pollution 21(2): 23-32. https://doi.org/10.3233/AJW240018.
[32] Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K., Hingorani, K. (2021): Towards a circular economy: an emerging economies context. – Journal of Business Research 122: 725-735. https://doi.org/10.1016/j.jbusres.2020.05.015.
[33] Peasgood, T., Mukuria, C., Brazier, J., Marten, O., Kreimeier, S., Luo, N., Mulhern, B., Greiner, W., Pickard, A. S., Augustovski, F., Engel, L., Gibbons, L., Yang, Z., Monteiro, A. L., Kuharic, M., Belizan, M., Bjørner, J. (2022): Developing a new generic health and

wellbeing measure: psychometric survey results for the EQ-HWB. – Value in Health 25(4): 525-533. https://doi.org/10.1016/j.jval.2021.11.1361.
[34] Pesaran, M. H., Vanessa Smith, L., Yamagata, T. (2013): Panel unit root tests in the presence of a multifactor error structure. – Journal of Econometrics 175(2): 94-115. https://doi.org/10.1016/j.jeconom.2013.02.001.
[35] Poncet, S., Starosta de Waldemar, F. (2013): Export upgrading and growth: the prerequisite of domestic embeddedness. – World Development 51: 104-118. https://doi.org/10.1016/j.worlddev.2013.05.010.
[36] Safi, A., Haseeb, M., Islam, M., Umar, M. (2023): Can sustainable resource management overcome geopolitical risk? – Resources Policy 87: 104270. https://doi.org/10.1016/j.resourpol.2023.104270.
[37] Safi, A., Kchouri, B., Elgammal, W., Nicolas, M. K., Umar, M. (2024): Bridging the green gap: Do green finance and digital transformation influence sustainable development? – Energy Economics 134: 107566. https://doi.org/10.1016/j.eneco.2024.107566.
[38] Sauerberg, M. (2021): The impact of population's educational composition on Healthy Life Years: an empirical illustration of 16 European countries. – SSM—Population Health 15: 100857. https://doi.org/10.1016/j.ssmph.2021.100857.
[39] Sharif, A., Kocak, S., Khan, H. H. A., Uzuner, G., Tiwari, S. (2023): Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: the dynamic role of green energy and green investment. – Gondwana Research 115: 98-106. https://doi.org/10.1016/j.gr.2022.11.010.
[40] Spash, C. L. (2007): The economics of climate change impacts à la Stern: novel and nuanced or rhetorically restricted? – Ecological Economics 63(4): 706-713. https://doi.org/10.1016/j.ecolecon.2007.05.017.
[41] Su, C.-W., Naqvi, B., Shao, X.-F., Li, J.-P., Jiao, Z. (2020): Trade and technological innovation: the catalysts for climate change and way forward for COP21. – Journal of Environmental Management 269: 110774. https://doi.org/10.1016/j.jenvman.2020.110774.
[42] Sumra, K., Iftikhar, H., Omerkhel, Q., Siddique, H. (2025): Promoting sustainable development goals through the Chinese concept of eco-civilization: a Delphi study of priority areas in the China–Pakistan Economic Corridor. – Asian Journal of Water, Environment and Pollution 22(1): 1-21. https://doi.org/10.36922/ajwep.8483.
[43] Wu, B., Ren, K., Fu, Y., He, D., Pan, M. (2024): Institutional investor ESG activism and green supply chain management performance: exploring contingent roles of technological interdependences in different digital intelligence contexts. – Technological Forecasting and Social Change 209: 123789. https://doi.org/10.1016/j.techfore.2024.123789.
[44] Xi, M., Chen, Y., Jiang, K. (2025): All roads lead to Rome? A contingent configurational perspective of HRM systems and organizational effectiveness. – Personnel Psychology. https://doi.org/10.1111/peps.12681.
[45] Xu, X., Xu, P., Bai, H. (2024): Working hours and household financial asset allocation. – Finance Research Letters 66: 105718. https://doi.org/10.1016/j.frl.2024.105718.
[46] Xu, Z. (2025): Harmony between nature and humanity: a systematic environmental governance approach to address climate change. – Energy & Environmental Sustainability 1(1): 100002. https://doi.org/10.1016/j.eesus.2025.01.001.
[47] Yun, L., Mao, Z. (2025): Psychological security, financial market participation, and residents' subjective well-being: an empirical analysis based on CFPS data. – International Review of Economics & Finance 97: 103744. https://doi.org/10.1016/j.iref.2024.103744.
[48] Zhang, J., Li, J., Yan, Y., Xie, Z. (2025): Concentration in cross-border research collaborations and MNCs' knowledge creation in a host country. – Strategic Management Journal. https://doi.org/10.1002/smj.70025.