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Life expectancy economic growth and resilience in resource constrained economies in the context of COVID-19 and the sustainable development goals

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Abstract

This study contributes to the sustainable development discourse by examining the interplay between health (life expectancy) and economic growth (EG), which is central to Sustainable Development Goals 3 (Good Health and Well-being) and 8 (Decent Work and Economic Growth). By investigating the dynamic relationship between Life Expectancy (LE) and EG, measured by LE rates and Per Capita Gross Domestic Product (PGDP), in 51 low and lower-middle-income countries from 1990 to 2023, with a particular focus on the disruptive impact of COVID-19. Employing Wavelet Coherence analysis, Granger Causality, and Johansen Cointegration tests, this study reveals critical relationships and identifies both short and long-term equilibrium linkages within health and economic systems. By explicitly situating the findings within the framework of the United Nations Sustainable Development Goals (SDGs), the study highlights how improvements in population health (SDG 3) and economic resilience (SDG 8) can be mutually reinforcing. It further provides evidence to guide policy interventions and sustainable development strategies. Further results indicate that, while the pandemic weakened short-term causalities, long-term cointegration remains intact, underscoring the need for integrated strategies that simultaneously strengthen health systems and promote inclusive EG. These insights provide critical guidelines for policymakers in resource-constrained contexts seeking to progress toward the SDGs and enhance resilience against future economic shocks. The findings provide insight into how health-system strengthening, and sustainable economic policies can jointly advance progress toward the SDGs.

Keywords Cointegration, Development economics, COVID-19, Economic growth, Granger causality, Life expectancy, Socio-economic inequalities, Wavelet coherences, Sustainable development goals

1 Introduction

There is a well-established causal relationship between LE and EG, with per-capita GDP reflecting a country income-generation capacity, while LE reflects the overall population health. Historical improvements in public health, nutrition, and sanitation increased both productivity and longevity [43], yet industrialisation and economic turbulence also produced health setbacks [39]. In low and lower-middle-income countries, structural constraints, including under-resourced health systems, limited fiscal space, and political instability, have slowed LE gains and widened inequalities. The health-wealth hypothesis posits reciprocal causation between health and income [15]. Recent evidence indicates that while better health can bolster productivity, weak systems and ineffective policies in low-income settings often disrupt this pathway [1].

Understanding these dynamics is critical not only for improving human capital but also for accelerating the global commitment to SDGs, as LE and EG are crosscutting enables for poverty reduction, resilience building, and sustainable development. Consistent with World Bank [48] evidence, substantial disparities persist between low and lower-middle-income groups. The COVID-19 pandemic further destabilised the health-growth relationship in resource-constrained economies. LE declined amid health-system strain, while economic growth faltered due to productivity losses and global slowdowns. The impact of COVID-19 is also documented by Austin Schumacher [6] and the World Bank (2024b), with pre-existing fragilities amplifying impacts [40]. Against this backdrop, the study investigates the dynamic LE-EG relationship, measured through LE and PGDP in 51 low and lower-middle-income countries, with particular focus on pandemic-era disruptions. By explicitly framing the analysis within the 2030 Agenda of SDGs, the study assesses the conditions under which health investments and income growth reinforce one another, generating decision-relevant evidence for advancing SDG 3 and SDG 8 in developing economies.

The COVID-19 pandemic profoundly disrupted global health and economic systems, with especially severe effects in low-income countries. Its long-term effects on LE and EG remain underexamined. Nevertheless, most existing studies focus on middle- and high-income economies, delivering limited suggestions from low- and lower-middle-income countries where structural fragilities amplify health and fiscal shocks, while conventional single-method time-series methods often fail to capture the combined short, medium, and long-term dynamics of the health economy nexus.

The study aims to analyse the short- and long-term causal linkages between LE and EG in low and lower-middle-income countries, also examining the impact of the COVID-19 pandemic. First, the study tests the direction of the short-term causal link between EG and LE using Granger Causality and Wavelet methods. Second, the study will examine potential long-term relationships between LE and EG using Cointegration and Wavelet analysis. Third, the study explores how the COVID-19 pandemic has altered these relationships in susceptible economies. Finally, this study provides empirical evidence on the health economic nexus, thereby informing sustainable development pathways and contributing to the achievement of SDGs 3 and 8.

This study also addresses three research questions. First, what are the short-run causal relationships between LE and EG in low and lower-middle-income countries? Second, do these countries share long-term equilibrium relationships between LE and EG?

Third, how has the COVID-19 pandemic disrupted or reshaped these short and long-term dynamics? In line with these questions, the following hypotheses are tested:

1. H1: LE and EG are cointegrated in the long run, reinforcing each other's trajectories.
2. H2: Short-run causal interactions are weak or inconsistent, particularly in resource-constrained economies.
3. H3: The COVID-19 pandemic further weakened short-run causalities but left long-run equilibrium linkages largely intact.

2 Literature review

The relationship between LE and EG, particularly PGDP, has been the focus of many studies. This relationship is often complex, multifaceted, context-dependent, and more substantial in low and lower-middle-income countries. Some studies suggest a positive relationship between LE and economic expansion [46]. Others argue that this effect is more subtle, with several key variables influencing the trajectory and strength of this relationship [13]. Identifying the variables that connect LE and EG can help illuminate gaps in current understanding and inform policy decisions. This relationship also matches the objectives of the SDGs, particularly Good Health and Decent Work and Economic Growth. It underscores the need to improve health with the right kind of inclusive economic development.

The theoretical foundations of this nexus highlight that longer life spans can significantly impact EG in low and lower-middle-income nations. According to Lowe [28] in the mainstream classical economic theory, Healthier people are more productive, boosting economic output Better health enables a more significant percentage of people in low-income nations to engage in labor-intensive industries vital to their economy. Healthier workers are more dependable, supporting higher-value businesses in lower-middle-income nations undergoing economic diversification. Furthermore, Mazumdar [29] noted that longer life expectancies help reduce mortality rates and health care costs, allowing more people to remain in the workforce and leading to EG.

Human capital theory also emphasizes how LE promotes investment in education and skill development [7, 12]. Longer life expectancies in low-income nations encourage greater prioritising of education, boosting literacy and skills. In contrast, in lower-middle-income nations, they drive investments in technical and higher education, thereby creating a more skilled workforce for economic transformation [8, 9, 22]**.** Despite these benefits, access to quality education remains underfunded in many areas, limiting its potential impact. Moreover, the relationship between monetary expansion and LE is complex and influenced by various factors, with some studies suggesting the short-term effects may be negligible without supporting elements like political stability, healthcare access, and education [34, 38]. Furthermore, in low-income nations, financial limitations sometimes impede health initiatives. Although sustainability remains an issue, Rahman et al. [36] indicates that foreign aid and private health investment perform better than government expenditure.

To strengthen the theoretical basis of this study, we explicitly link concepts from each framework to our analytical design. Classical theory posits that better health enhances productivity, while human capital theory suggests that increased longevity encourages greater investment in human capital, thereby influencing economic output over time.

Our econometric methods—Wavelet Coherence, Granger Causality, and Johansen Cointegration—enable these concepts to be operationalised simultaneously.

This study tests whether health improvements lead to productivity gains (classical health model) and whether longevity contributes to human capital accumulation and sustained growth (human capital model). By aligning theoretical ideas with the research design, we enhance the rigor of the study through grounding it in established economic theory. These theoretical foundations also reinforce the centrality of SDG 3 and SDG 8, underscoring the long-term benefits of improved health and education for sustainable economic growth.

Turning to evidence from low-income countries, empirical studies demonstrate that these nations have made remarkable progress in LE and EG, primarily driven by public health initiatives such as vaccination programs and improved access to health services [49]. For example, Rwanda's LE increased from 26.2 years in 1993 to 68.7 years in 2018, largely attributed to targeted health reforms (Iyakaremye, Tripathi, amp, & Business, 2024). These reforms reduced infectious diseases and increased labour force participation, positively impacting EG [12]. However, such studies often concentrate on success stories without accounting for external factors like foreign aid and global health partnerships that may have shaped these outcomes.

In contrast, Mozambique experienced a decline in LE in the early 1990s due to civil war and political instability [31]. Subsequent improvements in health services and international aid increased LE to 59.4 years by 2021. Yet political and economic barriers, including corruption and weak governance, have hindered the translation of health gains into sustained EG [33].

Moreover, the relationship between LE and EG is complex, as studies often struggle to isolate the effects of health reforms from other factors such as infrastructure and education. Variations in policy effectiveness, long-term dynamics, and limited data further constrain understanding. A more integrated development approach is therefore essential to link health improvements with sustainable economic growth.

Turning to evidence from lower-middle-income countries, improved LE supports EG by enhancing health outcomes and creating an environment conducive to foreign direct investment (FDI). Higher LE and productivity make these countries more attractive to investors. According to Aslan, Menegaki, and Tugcu [5], FDI inflows increase by 9% for each additional year of LE. Lower-middle-income nations also possess more diversified economies, with manufacturing, services, and agriculture driving robust growth, alongside advances in education, infrastructure, and workforce skills. By contrast, low-income nations face limited diversification and slower progress, restricting their capacity to leverage health improvements for EG.

In contrast, low-income nations often rely heavily on agriculture and face significant challenges, including limited access to infrastructure, healthcare, and education. The lack of diversification and slow progress in essential areas hinder the ability to leverage health advancements for EG. Consequently, while increases in LE can enhance financial outcomes, low-income nations struggle to create the conditions necessary for sustained prosperity. The income disparities between these groups emphasise the significance of integrating health into broader socioeconomic development strategies. The progress and setbacks in these countries serve as a reminder of the necessity of designing health and

economic policies to support the SDG agenda and, therefore, that increases in LE should also be directed toward sustainable and inclusive growth.

COVID-19 has profoundly reshaped the trajectories of EG and LE, especially in low and lower-middle-income countries. According to Aburto et al. [2], the pandemic decreased LE in 27 countries from 29. The study highlights that in Lithuania, male LE has fallen by 2.2 years, and that the increase in COVID-19 related deaths and the strain on health care systems are directly responsible for this decline. On the other hand, according to Gagnon, Kamin, and Kearns [18], the economic impact of the pandemic has been severe, exacerbating pre-existing vulnerabilities, especially in economically fragile countries.

Lockdowns, regulations, and sectoral downturns, such as in manufacturing and tourism, have severely disrupted regional economies [45]. Negeri [30] highlights that the pandemic has caused a global economic downturn, affecting jobs, output, and consumption. Moreover, nations with limited access to vaccines face prolonged health crises, further exacerbating the decline in economic activity and LE. In the post-pandemic period, improvements in LE and economic development were observed, particularly in countries with weak social safety nets and healthcare systems. The impact highlights the need for integrated recovery plans that address both economic and health challenges. These findings underscore the urgency of integrating pandemic recovery strategies within the SDG framework, particularly by strengthening health system resilience and inclusive economic recovery.

Previous studies by Karunarathne et al. [26] found that COVID-19, healthcare expenditure, and per capita income jointly influence LE in lower-income countries and emphasised the depth of structural vulnerabilities in developing countries. Jayadevan, Hoang, and Yarram [24] emphasised that healthcare expenditure was vital to maintaining the growth trajectory during the pandemic in developing economies, mostly those with frangible fiscal space. Edward Miguel [17] assesses the spill over consequences of health crises on economic performance in poor economies, while Adedokun, Egbelakin, and Omotayo [3] found that income losses directly diminished well-being levels. Decerf et al. [16] also examined how life, income and education losses were largest for low- and lower-middle-income developing countries. Collectively, these studies also provide an era of original contributions to the developing research, while putting our work into the developing body of literature, particularly the focus on temporal moments using the Wavelet, Granger, and Cointegration approaches.

Finally, the gaps in the literature remain striking. Life expectancy and EG in the modern world have been widely studied. However, there are significant disparities between low and lower-middle-income countries. Health interventions are crucial during the COVID-19 pandemic; many studies ignore their considerable benefits. The survey by Ridhwan et al. [37] provides insights into the broader health-economic nexus. However, it does not address how global crises affect EG and LE in resource-constrained settings.

Moreover, in low-income settings, the immediate effects of health shocks on economic indicators are often overlooked in favor of longer-term trends. Alam and Mahal [4] study how economic indicators respond to health crises. However, such studies cannot fully reflect the immediate consequences, or the complex challenges that low-income nations face during such crises.

These gaps highlight the need for a focused study on the short and long-term impacts of health shocks on economic performance in low and middle-income countries. Exploring how health interventions can mitigate economic setbacks and strengthen resilience is crucial. This study seeks to address these gaps by examining the bidirectional relationship between health crises, LE, and EG in vulnerable countries, an area underexplored in current literature. By situating this consideration within the SDGs, this research contributes to global policy discussions on sustainable development in impoverished contexts, while addressing empirical and methodological deficiencies.

Although studies by Omotayo and Ogunniyi [32] and Decerf et al. [16] provided new insights into the health and economic turmoil caused by the pandemic, we have an incomplete understanding of how health growth interactions in the short-run and long-run are disentangled in developing economies. As a result, we contribute uniquely to literature. We apply time–frequency and causality techniques to low and lower-middle-income developing countries, which allow us to estimate both immediate shocks to the GDP growth health interaction, as well as long-term equilibria during the COVID-19 period.

3 Data and methodology

3.1 Data sources and variables

Considering the data availability, this study utilises a dataset comprised of 51 nations belonging to the low and lower-middle-income categories from 1990 to 2023. Supplementary material appendix 1 contains the dataset used in the study. The PGDP and LE data from 1900 to 2022 were sourced from the World Bank database, as detailed in Table 1.

The dataset was created by identifying 51 developing countries recognised by the World Bank as low- and lower-middle-income economies. These countries were selected based on the completeness of data for this entire period (1990–2023), with both PGDP and LE equivalent to a coverage of at least 95%. This coverage combines developments that capture long-term development processes as well as the specific effects of the COVID-19 pandemic. By analysing developing economies, this dataset permits a standardised analysis of how health systems as well as economic systems interact during crises while explicitly addressing resource constraints. Values for 2023 were incorporated using forecasting methods to ensure full coverage of the study period.

The empirical study by Bayar [10] has provided strong support for including these variables, highlighting their importance in analysing development dynamics in many economic domains. In contrast to PGDP, which measures economic success, LE measures population health. Both metrics are essential for investigating how EG and health interact in environments with limited resources.

Table 1 Variables with definitions, units, and data sources *Source*: Authors' illustrations based on world bank database

Variable	Source	Unit of measure
Life Expectancy	World Bank Database https://data.worldbank.org/indicator/SP.DYN.LE00.IN	Number of Years
Economic Growth	World Bank Database https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?view=chart	Current International US $

3.2 Pre-processing and forecasting

The pre-processing phase basically involved several key steps, comprising data cleaning, scaling, and transformation, to confirm the dataset was refined and optimised for analysis. Stability checks were performed to assess the data's suitability for time series modelling, with the Augmented Dickey-Fuller test confirming its readiness. The latest available PGDP data, updated through 2023, was sourced from the World Bank database for the analysis. As the 2023 LE data was not yet available, regression analysis was employed to estimate the values, ensuring the dataset remained both comprehensive and current for this study. PGDP values for 2023 were obtained directly from the World Bank, whereas LE values for 2023 were forecasted using polynomial regression. The forecasts were carefully validated to provide a complete and up-to-date panel dataset for the study.

Stationarity and robustness were further confirmed using ADF (Augmented Dicky Fuller) and PP (Phillips-Perron) tests. Missing or anomalous values were addressed, and regression parameters for LE forecasts were optimised to minimise prediction errors.

3.3 Econometric methods

This study employs a mixed econometric framework to investigate the relationship between LE and GDP growth, integrating Wavelet Coherence, Granger causality, and Johansen cointegration techniques. By combining these methods, the analysis captures short-run predictive dynamics, medium-term fluctuations, and long-term equilibrium relationships that single-process time series approaches cannot achieve. Lag lengths for Granger causality and Johansen cointegration were determined using AIC, BIC, and trace/max eigenvalue statistics, and sensitivity analyses with alternative lag structures were conducted to ensure the robustness of both short- and long-term relationships.

3.3.1 Wavelet coherence analysis

Wavelet analysis is a powerful technique for exploring short, medium, and long-term relationships by decomposing data into various time scales. Wavelet Coherence differs from traditional time-series methods in that it shows localised patterns about relationships through time and frequency domains, which is particularly effective in identifying the disruptive and recovery phases of crises such as the COVID-19 pandemic. Wavelet Coherence offers better insights, as it depicts not only immediate shifts, but also longer-term directional co-movements.

Recent examples have shown it to be relevant to pandemic-related research; for example, Galappaththi et al. [19] and Goupillaud, Grossmann, and Morlet [20] looked at wavelet coherence in a COVID-centered setting, while the environmental studies Anthropogenic Disturbance During COVID-19 [44] and Syed et al. [42] used wavelet methods to assess economic and health shocks triggered by the pandemic. These examples illustrate an increasingly important aspect of wavelet coherence approaches that dynamically explore non-stationary relationships. In this study, wavelet scales and mother wavelet functions were carefully optimised based on prior literature and the frequency characteristics of LE and PGDP, thereby enhancing the interpretability of short, medium, and long-term co-movements.

3.3.2 Granger causality test

The Granger Causality test measures the extent to which the past values of one variable can predict the future values of the target variable. This study attempts to determine whether the past rates of change in life expectancies can predict PGDP, or vice versa. Granger causality, described by Granger [21] and expanded upon by [41] identifies Granger causality when lagged rates of change in one variable have explanatory power for the movements in another variable. Granger causality is useful because it provides a short-run predictive dynamic for variables and can help inform the interpretation of Wavelet Coherence. Wavelet will identify co-movement with different time horizons, while Granger provides directionality for the short-run effects.

3.3.3 Johansen cointegration test

The Johansen cointegration technique looks for long-run equilibrium relationships between LE and PGDP. Cointegration means that the two variables, while non-stationary, move together for the long-run and there is a consistent equilibrium relationship between the two variables.

In this study, the Johansen Cointegration analysis provides an important complement to Wavelet and Granger. Wavelet allows for time–frequency relationships that slowly change over time, while Granger tests for short-run predictive causality. Cointegration tests determine whether LE and PGDP move towards a common long-run path. This is especially important for understanding the long-run implications of health improvements on EG, or vice versa [25].

3.4 Methodological workflow

The methodology flowchart in Fig. 1 describes how to analyse the link between LE and EG using data from the World Bank database. First used Wavelet Coherence to evaluate information in terms of time–frequency co-movements across short, medium, and long horizons. Second, Granger causality was used to assess the direction of the short-run predictive relationships. Finally, Johansen cointegration analysis was used to assess if there were stable long-run equilibria. By integrating three time-series methods, we provide a more integrated framework for understanding the dynamic multidimensional health-economy nexus than conventional time-series models that only consider short-run causality or long-run correlations.

4 Empirical results and discussions

4.1 Descriptive analysis

As a result, Fig. 2 boxplot analysis presents the descriptive statistics of the dataset (see Supplementary material appendix 2 for full details). The figure illustrates stark inequalities between lower-middle-income and low-income countries, highlighting disparities in both health and economic outcomes. Descriptive statistics highlight inequalities between countries, consistent with human capital theory [12]. The lower average LE observed in low-income countries reflects their limited capacity to transform economic gains into human capital. This underscores why targeted investment in primary healthcare and education is critical for unlocking long-run EG. These cross-country differences relate directly to the sustainable development agenda: disparities in LE and PGDP map onto SDG 3 and SDG 8 and signal the need for policies prioritising developing countries.

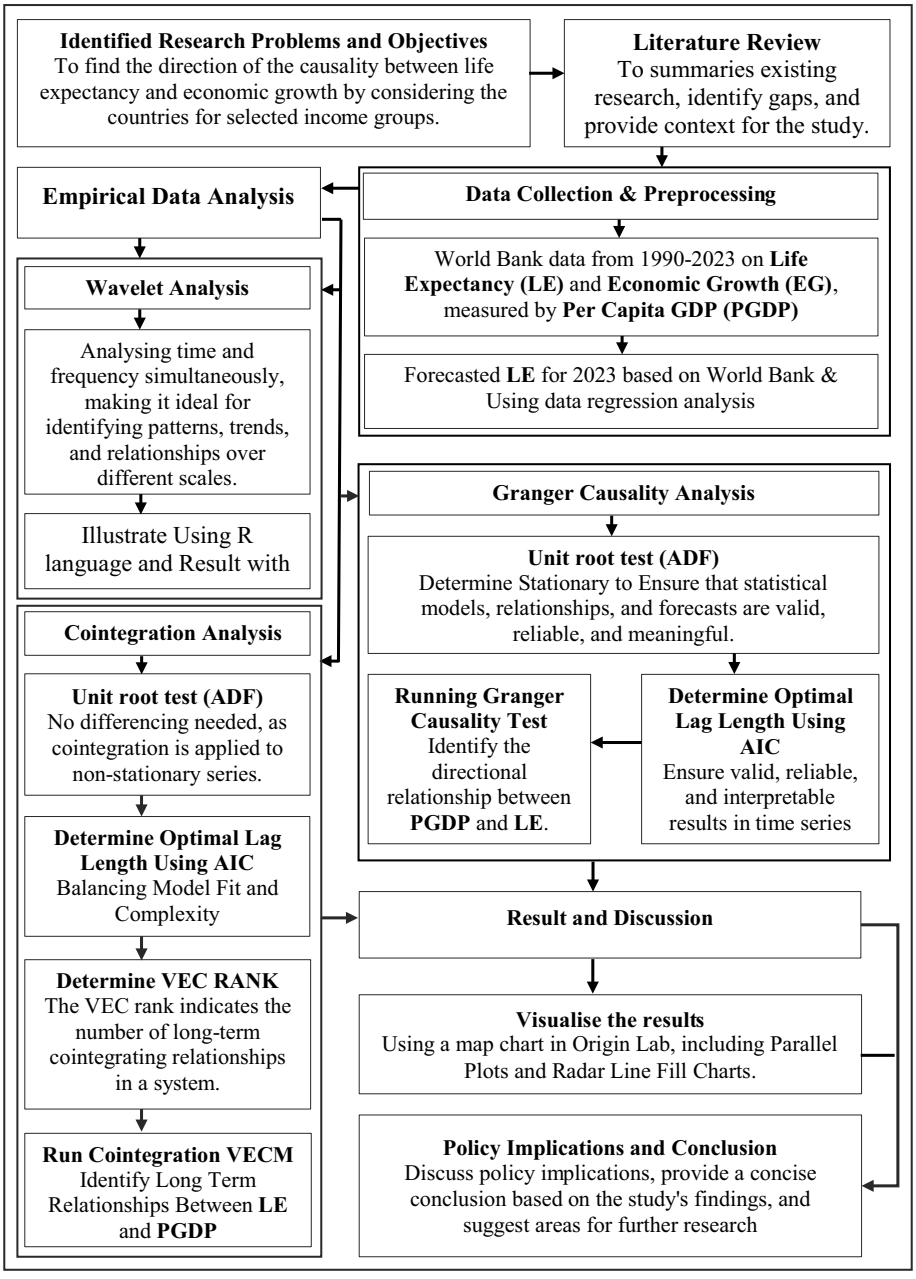

Fig. 1 Research workflow connecting data sources, analytical methods, and resulting outcomes. *Source*: Authors' illustrations

Before COVID-19, low-income nations exhibited low average PGDP ($1,394.35) and LE (54.87 years) and showed limited variability (PGDP: $287.68-$4,684.09; LE: 14.09–67.12 years), reflecting persistent economic and health challenges. Lower-middle-income countries had higher averages PGDP ($3,982) and LE (63.58 years) and display wider ranges (PGDP: $437.99-$18,816.51; LE: 41.89–76.61 years), indicating greater development potential. Post COVID-19, low-income countries faced stagnating or declining PGDP and setbacks in LE due to setbacks caused by strained healthcare systems, though some, such as Rwanda, showed resilience. Lower-middle-income countries exhibited mixed trends, with faster recovery in diversified economies like Bangladesh but intensified declines in vulnerable nations like Sri Lanka. These trends highlight the

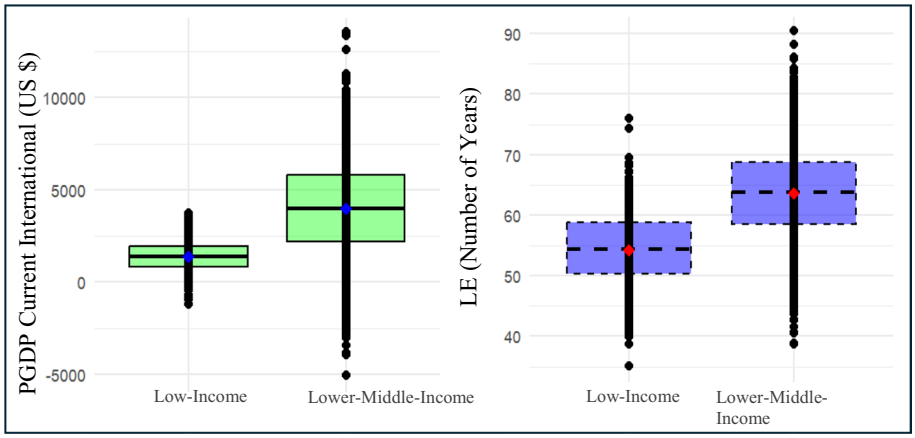

Fig. 2 Distribution of LE and PGDP in Low and Lower-Middle-Income Countries *Source*: Authors' illustrations

need for targeted investments in healthcare, economic diversification, and social safety nets to mitigate disparities and enhance resilience. In SDG terms, this requires stronger health systems (SDG 3.8) combined with inclusive and diversified growth strategies (SDG 8.1/8.2) to reduce vulnerability to shocks.

Figure 3 illustrates parallel plot comparing the link between PGDP and LE across 51 low- and middle-income countries, revealing general trends and key exceptions. While higher PGDP typically correlates with longer LE, political instability, healthcare access, and social disparities significantly influence health outcomes. Therefore, progress on SDG 3 and SDG 8 may depend not only on income growth, but also on governance and equitable access to critical services in developing countries.

With a PGDP of $3,269.24, Sudan continues to face major health challenges due to political instability and inadequate healthcare infrastructure [14]. In contrast, Mozambique ($845.55 PGDP, 74.35 LE) and Rwanda ($1,266.66 PGDP, 70.08 LE) illustrate how effective health policies can enhance LE despite limited resources. As noted by Kelly et al. [27] and Webb [47], Kiribati and the Solomon Islands demonstrate how strong governance and healthcare systems enable high LE, despite limited economic resources. The experiences of these countries provide some concrete pathways for SDG 3: making investments in primary care, developing a prevention culture, and equitable coverage of health services, even with limited fiscal space, while achieving SDG 8 via jobs-rich and health-enabling sectors.

However, the COVID-19 pandemic reduced LE in over 20 countries, including Eswatini and Nigeria, even as average PGDP increased. This underscores that EG alone is insufficient to improve public health. Sustainable improvements in LE require holistic approaches, including robust healthcare systems, social equity, and political stability. These factors are essential to building resilience and safeguarding public health, particularly during crises. This result reaffirms the interconnections of SDG 3 and SDG 8: short-term growth without simultaneous investment in health does not result in sustainable improvements in population well-being.

Figure 4 presents a radar line fill plot illustrating the impact of the COVID-19 pandemic on the relationship between PGDP and LE in low-income countries. In the plot, yellow and blue colours represent the average of the five years before COVID-19,

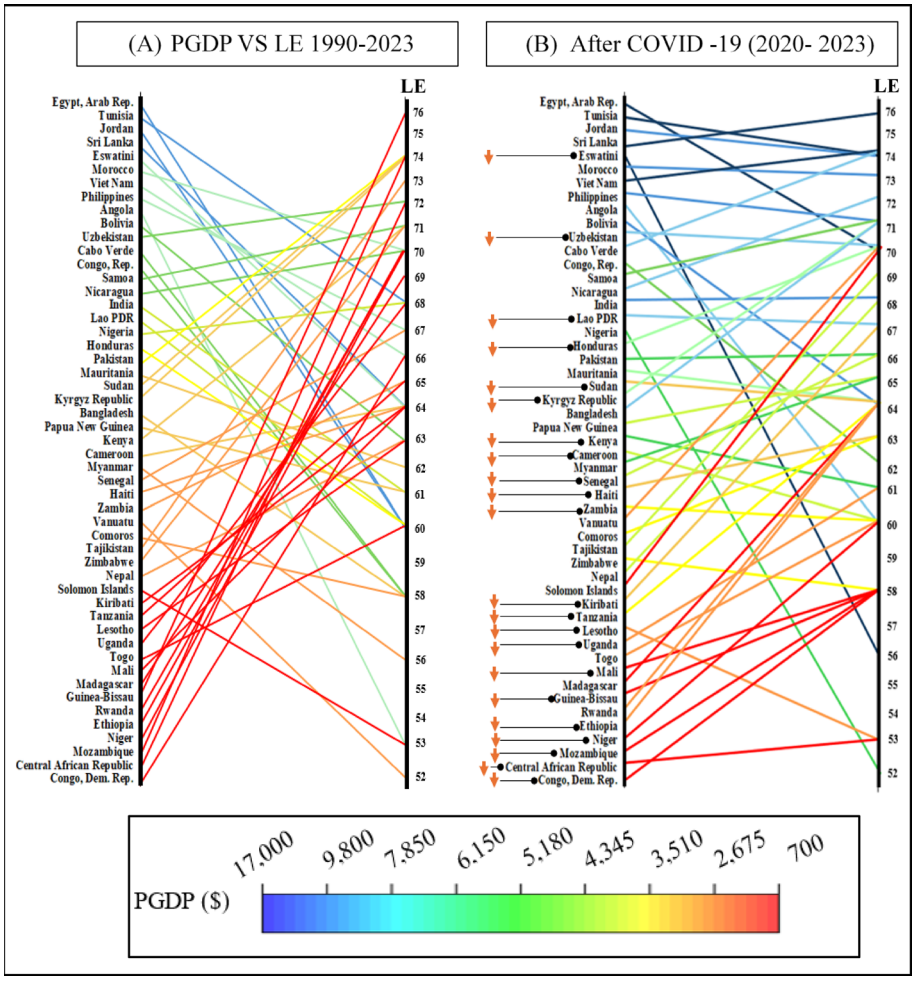

Fig. 3 Parallel Plot Comparing LE and PGDP Before and After COVID-19 *Source*: Authors' illustrations. Note: Red downward arrow indicates decreased PGDP values in the respective countries.

whereas yellow and green colours represent the average LE and PGDP during the five-year post-COVID-19 period.

Since the pandemic, countries such as Sudan and Madagascar have experienced EG but only modest improvements in LE. At the same time, Rwanda and Ethiopia have shown resilience in maintaining LE despite low PGDP, underscoring the critical role of adequate health care policies. However, in some countries, despite high average PGDP and LE values, LE at birth has declined significantly in other countries due to pandemic-related challenges. The observation of these trends suggests an emphasis in policy on resilient primary care, vaccination, and essential services, and inclusive labour markets and socio-protective coverage of vulnerable workers.

Figure 5 illustrates the impact of the COVID-19 pandemic on the relationship between PGDP and LE in lower-middle-income countries.

Sri Lanka, Vietnam, and Jordan have maintained high PGDP and LE values. In contrast, countries such as Eswatini, Nigeria, Angola, and Kenya have experienced significant LE declines due to pandemic-related pressures. These data highlight that EG alone is insufficient to improve LE and that strong healthcare infrastructure, political stability, and effective social policies are crucial to maintaining and enhancing LE.

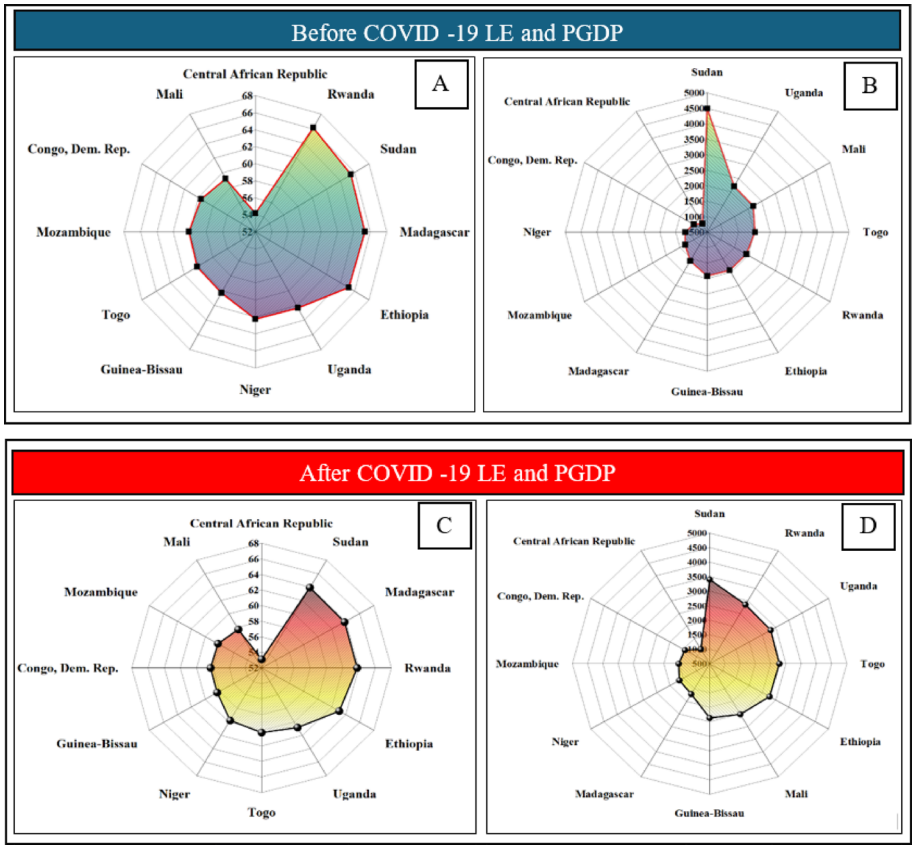

Fig. 4 Radar Plot Comparison of LE and PGDP Before and After COVID-19 in Low-Income Countries *Source*: Authors' illustrations using Origin Lab

4.2 Wavelet coherence analysis

Wavelet coherence analysis is one of the methods used to study dynamic relationships between specific time series. It allows researchers to investigate the temporal and frequency-based dynamics between PGDP and LE over time and under different conditions. Figure 6 presents a Wavelet Coherence analysis illustrating the dynamic interaction between PGDP and LE across different time scales. Methodologically, identifying time-scale-specific linkages clarifies when and how policy can most effectively support SDG 3 and SDG 8 short-run buffering versus long-run system building.

4.2.1 Pre-COVID dynamics of life expectancy and PGDP

The time-scale interactions are divided into short-term (0–8 years), medium-term (8–32 years), and long-term (32–128 years). The relationship between LE and PGDP between 1990 and 2019 shows a dynamic, bidirectional pattern. In the short-term, between 1991 and 2003, 2007–2012, and 2018, the arrows pointing upwards from the right indicate that LE positively affected PGDP, emphasising the role of health in EG. In contrast, between 1994 and 1997 and 2010, the arrows pointing upwards from the left suggest that LE negatively affected PGDP, reflecting the economic stress associated with health improvements. Additionally, in 2000 and 2009, the arrows from the left show that PGDP LE was negatively affected, indicating economic downturns that affected health outcomes. This pre-COVID analysis highlights the complex interdependence between health and EG over time. These pre-COVID patterns align with SDG rationales: health

Fig. 5 Radar Plot Comparison of LE and PGDP Before and After COVID-19 in Lower Middle-Income Countries
Source: Authors' illustrations using Origin Lab

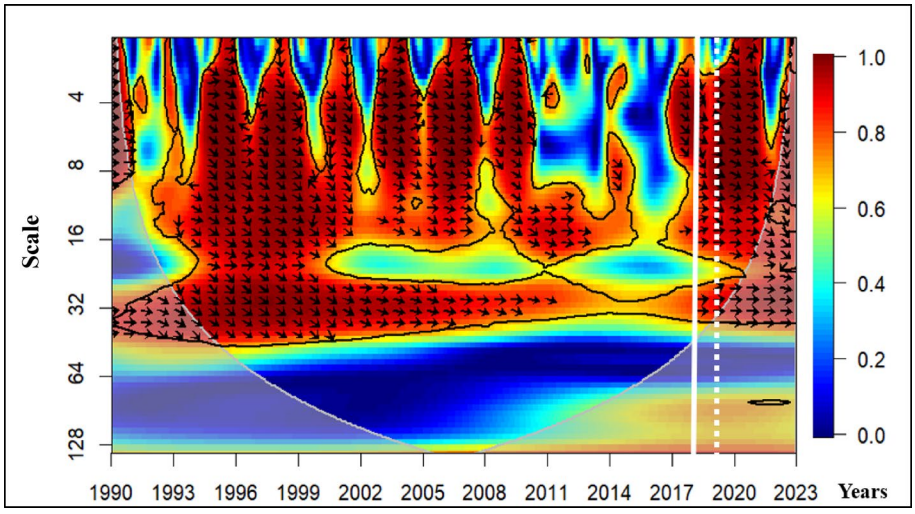

Fig. 6 Wavelet Coherence between LE and PGDP in Low-Income Countries.
Source: Authors' illustrations using R studio. Note: The arrows in the wavelet coherence plot indicate the phase relationship between LE and PGDP. Rightward arrows (→) show they move together (in phase), while leftward arrows (←) indicate they move oppositely (out of phase). Upward arrows (↑) suggest LE leads PGDP, and downward arrows (↓) mean PGDP leads LE. Solid Line: Represents the period before COVID-19 (1990 to 2019), capturing the pre-pandemic period. Dashed Line: Represents the period after COVID-19 (2020 to 2023), showing the post-pandemic period

investment (SDG 3) can lead to productivity and earnings (SDG 8) over time, even though short-run adjustment costs sometimes manifest.

4.2.2 Post-COVID shifts in relationships

The post-COVID period marks significant shifts in the dynamics between LE and PGDP, primarily shaped by the pandemic's socio-economic impact. In 2019, arrows pointing upwards to the left indicate that LE negatively affected PGDP in the short term, reflecting the initial challenges of managing EG alongside health outcomes. Similarly, in 2022, arrows pointing upwards to the left highlight that LE negatively influenced PGDP in the medium term, demonstrating ongoing difficulties in balancing these priorities. However, the period from 2019 to 2023 also saw arrows pointing downwards to the right, indicating that PGDP positively influenced LE across all time scales. This trend underscores a post-COVID recovery phase, where EG increasingly supports improvements in health outcomes. This post-COVID shift reflects the mortality and productivity shocks documented by Aburto et al. [2] but also supports Jayadevan et al. [24] and Karunarathne et al. [26], who show that healthcare spending and economic recovery jointly determine LE in fragile systems. The emergence of PGDP-led improvements in LE aligns with SDG 8-to-SDG 3 spill overs during recovery, emphasising the need to protect health budgets as economies rebound.

4.2.3 Insights across short, medium, and long-term horizons

In the short term, the pre-COVID period indicates that LE often positively influenced PGDP, with some exceptions where economic pressures reversed the effect. Post-COVID, short-term interactions revealed more significant challenges, with LE negatively affecting PGDP during specific years. Medium-term trends revealed more significant disruptions post-COVID, reflecting lingering pandemic impacts. Over the long term, both periods highlight the cumulative benefits of sustained EG on LE. The post-COVID recovery emphasises the growing importance of PGDP in driving health improvements, reinforcing the critical relationship between financial and health dynamics. Short-term disruptions echo on income losses and well-being, while medium-term instability reflects the structural scars highlighted by Decerf et al. [16]. Yet, the persistence of the long-run equilibrium reinforces [36], who stressed the enduring role of healthcare expenditure in sustaining outcomes.

Figure 7 explores the dynamic relationship between EG (PGDP) and LE over the short-term (0–16 years), medium-term (16–64 years), and long-term horizons, in Income countries, comparing the periods 1990 to 2019 (pre-COVID) and 2020 to 2023 (post-COVID).

4.2.4 Pre-COVID dynamics of life expectancy and PGDP

The pre-COVID period revealed a generally positive correlation between PGDP and LE. Most arrows pointed to the right, suggesting that EG often aligned with better health outcomes. However, short-term deviations were noted, such as the lower right arrow and the leftward arrows in 2009 and 2011, indicating a negative relationship between PGDP and LE. These findings highlight a bidirectional relationship in which LE and PGDP dynamically influence each other. This bidirectionality resembles the concept of SDG co-benefits: health advances (SDG 3) and decent work (and productivity) (SDG

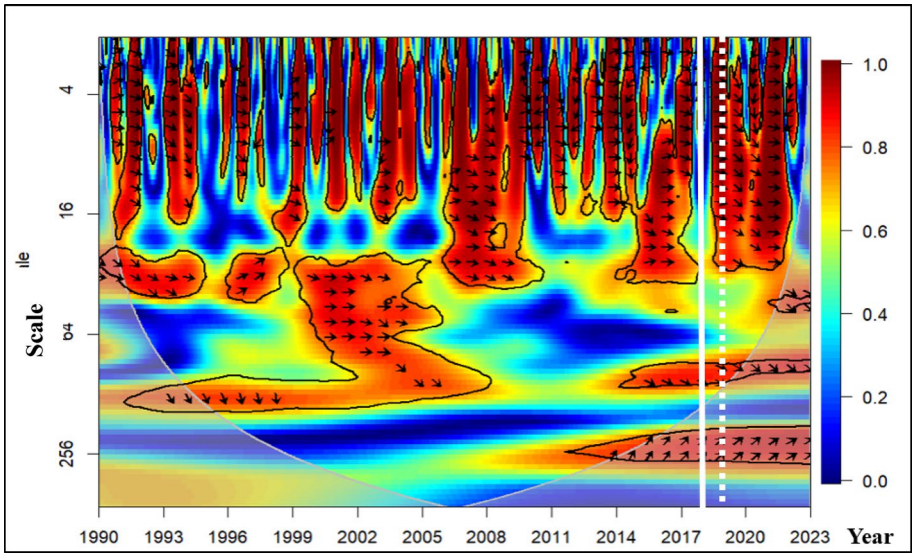

Fig. 7 Wavelet Coherence between LE and PGDP in Lower Middle-Income Countries *Source*: Authors' illustrations using R studio. Note: The arrows in the wavelet coherence plot indicate the phase relationship between LE and PGDP. Rightward arrows (→) show they move together (in phase), while leftward arrows (←) indicate they move oppositely (out of phase). Upward arrows (↑) suggest LE leads PGDP, and downward arrows (↓) mean PGDP leads LE. Solid Line: Represents the period before COVID-19 (1990 to 2019), capturing the pre-pandemic period. Dashed Line: Represents the period after COVID-19 (2020 to 2023), showing the post-pandemic period.

8) are mutually reinforcing over terms of development. This complex interplay illustrates how improvements in health could promote EG, while economic challenges could impede health outcomes.

4.2.5 Post-COVID shifts in relationships

In the post-COVID period, distinct changes emerged. Rightward to down arrows indicated that PGDP positively impacted short- and medium-term LE, showing signs of recovery. However, in 2022, leftward to down arrows revealed a negative short-term impact of PGDP on LE, highlighting the disruptive effects of the pandemic on the previously positive relationship between these variables. This shift underscores the evolving and context-dependent nature of the health-EG nexus during this challenging period. The positive PGDP-led recovery post-COVID confirms findings by Karunarathne et al. [26], though the negative short-term effects parallel. By mapping out these shifts, policymakers can optimise stage SDG-compliant recoveries by protecting essential health services during downturns and utilising growth to restore health outcomes. Consistent with Objective 3, the post-COVID wavelet patterns reveal negative short- and medium-term disruptions, where declines in LE reduced PGDP in the immediate years following the pandemic. However, the persistence of the long-run equilibrium indicates resilience in the health–economic nexus, albeit uneven across regions.

4.2.6 Insights across short, medium, and long-term horizons

Short-term interactions during both periods were dynamic, with pre-COVID showing predominantly positive influences, while post-COVID exhibited mixed effects due to pandemic-related disruptions. Medium-term dynamics varied significantly; during pre-COVID, EG and health displayed complementary trends, whereas post-COVID, medium-term disruptions became more apparent, reflecting the lasting impacts of the

pandemic on socio-economic systems. Long-term trends, however, consistently emphasised the mutual reinforcement between economic growth and health, highlighting the need for balanced health and monetary policies to ensure sustainable development. In practice, this points to SDG policy mixes that pair counter-cyclical health protection (SDG 3) with inclusive employment and productivity measures (SDG 8).

4.3 Granger causality and Johansen cointegration analysis

Table 2 shows the results of the Granger Causality Analysis (See Supplementary material appendix 3) and the cointegration analysis that shows the dynamic relationship between LE and PGDP in low-income countries. The short-run causality tests as well as the long-term cointegration results have their direct implications on SDG planning, especially the differentiation between short-term goals and the long-term structural reforms.

4.3.1 Results for low-income countries

4.3.1.1 Short-term dynamics Granger analysis, focusing on short-term processes, reveals diverse causal relationships between PGDP and LE across countries. No short-run causality was detected in Congo, Madagascar, and six other Central African nations, indicating limited immediate interactions between these variables. Conversely, Rwanda demonstrated a bidirectional relationship, suggesting reciprocal influences between economic development and health outcomes. Unidirectional causality was observed in Mozambique, where LE positively impacted PGDP. These variations highlight the complexity and context-specific nature of short-term dynamics between health and EG. Where short-run causality is weak or absent, SDG-consistent policy should prioritise shock absorbers, essential health services, income support, and employment safeguards to protect human capital during crises. Highlighting objective 1, The Granger causality results indicate that short-run causalities are generally weak or inconsistent across many low-income countries. This suggests that immediate economic gains do not systematically translate into better health outcomes. These findings reinforce H2 and align

Table 2 Short and Long run causality results between LE and PGDP in low-income countries

Low–Income Countries						
Country	Causality	Cointegration Unit root			$p > chi^2$	Cointegration
		MPPt	PPt	ADFt		
Central Africa	DPGDP←//→ DDLE	0.7959	1.1935	1.2907*	28.17***	**Yes**
Congo, Dem. Rep.	DPGDP←//→ DDLE	1.6184*	2.7174***	5.8160***	4.26**	**Yes**
Ethiopia	DPGDP → DDLE	2.6001***	4.3746 ***	7.2961***	23.20***	**Yes**
Guinea-Bissau	DPGDP → DDLE	3.1007***	5.4013***	5.1786***	57.78***	**Yes**
Madagascar	DPGDP←//→ DDLE	1.1800	2.1180**	2.6622***	56.00***	**Yes**
Mali	DPGDP←//→ DDLE	3.9686***	5.7551***	5.7232 ***	133.5 ***	**Yes**
Mozambique	DPGDP ← DDLE	1.6970**	2.6412***	4.9301***	366.31***	**Yes**
Niger	DPGDP←//→ DDLE	2.8432***	5.2800***	9.1202***	81.820***	**Yes**
Rwanda	DPGDP ↔ DLE	1.7319**	2.8761***	2.9526 ***	2.827*	**Yes**
Sudan	DPGDP←//→ DDLE	–1.4577*	–1.8870**	–1.8973**	147.18***	**Yes**
Togo	DPGDP → DDLE	3.2408***	4.2448***	6.7111 ***	42.61***	**Yes**
Uganda	DPGDP → DDLE	1.8621**	2.7950***	4.3955 ***	5.19**	**Yes**

LE causing PGDP is depicted by (←), PGDP causing LE is shown by, (→) Bidirectional causality between LE and PGDP is described by (green coloured ←→) and countries with No Causality between LE and PGDP is depicted by (red coloured ←//→)

Green shading indicates the presence of long-run cointegration (Yes), while red shading indicates no cointegration (No).

Unit root Tests: *MPPt* Modified Philips Peron test, *PPt* Philips Peron test, *ADFt* Augmented Dickey-Fuller test. (Significance level at *10% **5% and ***1%)

Bidirectional cases such as Rwanda, Mali, and Niger align with the health-wealth hypothesis (D. [11, 15]). By contrast, unidirectional causality from PGDP to LE in Ethiopia, Togo, and Uganda reflects the income-led pathway [34, 35], while Mozambique and Guinea-Bissau illustrate health-led growth consistent with human capital theory.

with Preston [34] perspective that structural barriers often constrain short-term linkages between economic growth and health.

4.3.1.2 Long-term equilibrium Cointegration analysis confirms a robust long-term relationship between LE and PGDP across all countries, reflecting a stable and enduring connection. Nations such as Mali, Mozambique, Niger, Rwanda, Sudan, Togo, and Uganda provide compelling evidence of this equilibrium. Furthermore, the significance of the unit root test in countries like Ethiopia and Guinea-Bissau further supports this long-term relationship. The results from these nations indicate stationarity in the residuals of the Cointegration equation, validating the existence of a stable equilibrium over time. These findings emphasise the mutual reinforcement of health and EG, underscoring the importance of sustained investments in both areas to achieve long-term development goals.

Table 3 demonstrates the results of the Granger Causality Test, which had analysed variables; PGDP and LE for 39 lower-middle-income countries from 1990 to 2023, along with the respective cointegration test results. This supports long-horizon SDG strategies: scaling primary care, preventive health, and skills formation to entrench the observed equilibria. In line with objective 2 the Johansen cointegration results confirm a long-run equilibrium between LE and PGDP in the majority of countries. This supports H1, suggesting that sustained improvements in health and income reinforce each other's trajectories, despite short-term volatility.

The absence of short-term causality in many countries (Congo, Eswatini, Haiti) indicates that EG has not been systematically channeled into health outcomes. These findings support Preston [34] argument that income alone is insufficient without institutional reforms. By contrast, the bidirectional causality observed in countries such as the Philippines and Morocco illustrates the potential for virtuous cycles, where health outcomes stimulate growth and growth, in turn, reinforces health improvements a dynamic consistent with Deaton [15] health-wealth hypothesis.

These findings align with Bloom et al. [12], who emphasised the productivity gains from improved health, but they also echo the caution of Rocco et al. [38], who noted that such relationships may be inconsistent in resource-constrained economies.

4.3.2 Result for lower-middle-income countries

4.3.2.1 Short-term dynamics Granger causality tests in low and lower-middle-income countries reveal minimal short-term connections between LE and PGDP. In 18 countries within the lower-middle-income group, no causal relationships were detected. However, five countries, including Morocco, Nicaragua, and Senegal, exhibited a bidirectional causal relationship, highlighting the reciprocal influences between health and EG. Only 12.8% of countries demonstrated unidirectional causality from LE to PGDP, with examples such as Bangladesh, Bolivia, and India. Furthermore, in 10 countries, changes in PGDP were found to affect LE, illustrating context-specific short-term dynamics. Where short-run links are weak, SDG-consistent policy design should emphasise continuity of essential health services and employment protections to preserve human capital during shocks.

4.3.2.2 Long-term equilibrium Cointegration tests indicate that 29 out of 39 lower-middle-income countries exhibit a significant long-term relationship between LE and PGDP. This suggests a stable interdependence between EG and health over time. Interestingly,

Table 3 Short and long run causality results between LE and PGDP in lower-middle- income countries

Lower Middle–Income Countries						
Country	Causality	Cointegration Unit root			$p > chi^2$	Cointegration
		MPP t	PPt	ADFt		
Angola	DPGDP←//→ DDLE	–0.8267	–1.3623*	–0.9875	144.37***	Yes
Bangladesh	DDPGDP → DLE	1.8857 **	3.3762 ***	4.7277***	1.969	No
Bolivia	DPGDP → LE	1.9501**	4.1852***	6.2609***	0.174	No
Cabo Verde	DPGDP → DDLE	2.6166***	3.9870 ***	4.0026***	364.55***	Yes
Cameroon	DPGDP ← DDLE	2.0153**	3.1216***	5.9678***	0.561	No
Comoros	DPGDP ← DDLE	2.5898***	3.6210***	4.873***	52.02***	Yes
Congo, Rep.	DPGDP←//→ DDLE	–0.1724	0.3408	0.5343	12.45***	Yes
Egypt, Arab Rep.	DPGDP ← DDLE	2.2859*	4.1897***	8.2811***	0.034	No
Eswatini	DPGDP←//→ DDLE	1.6743**	3.9661 ***	4.7804***	13.78***	Yes
Haiti	DPGDP←//→ DDLE	–0.3579	–0.4355	–0.6319	55.91***	Yes
Honduras	DPGDP←//→ DDLE	1.2972*	2.1317**	2.1191**	3.293*	Yes
India	DDPGDP → DLE	3.0957***	6.1642***	7.8438***	44.29***	Yes
Jordan	DPGDP←//→ DDLE	0.1776	0.6284	2.1718**	564.64***	Yes
Kenya	DPGDP←//→ DDLE	2.1088 **	3.7753***	6.752 ***	2.297	No
Kiribati	DPGDP → DDLE	2.3679***	3.7541***	5.5922***	1.380	No
Kyrgyz Republic	DPGDP → DDLE	2.4058***	3.4179***	3.4064***	0.098	No
Lao PDR	DPGDP←//→ DDLE	2.7025***	4.1242***	4.767***	6.070**	Yes
Lesotho	DPGDP ← DDLE	1.4390 *	2.0468 **	2.3062 **	44.180***	Yes
Mauritania	DPGDP←//→ DDLE	2.8858***	5.0635***	5.4920***	170.98***	Yes
Morocco	DPGDP ←→ DLE	1.8429 **	2.7278 ***	2.7197***	39.650***	Yes
Myanmar	DPGDP ← DLE	–1.7567**	–1.0710	–1.2864*	53.860***	Yes
Nepal	DPGDP←//→ DDLE	2.3177***	4.5158***	5.200 ***	3.200*	Yes
Nicaragua	DPGDP ←→ DLE	3.1309***	4.8363 ***	4.590 ***	0.865	No
Nigeria	DPGDP → DLE	1.1785	2.2616 **	2.3080**	1383.3***	Yes
Pakistan	DPGDP ←→ DLE	3.0055***	4.3881 ***	5.530 ***	123.23***	Yes
PNG	DDPGDP → DLE	1.4903*	2.4797 ***	2.4974***	107.21***	Yes
Philippines	DPGDP ←→ DLE	1.6867**	2.8516***	1.9739 **	10.670***	Yes
Samoa	DPGDP←//→ DDLE	0.2382	0.6043	0.6315	29.700***	Yes
Senegal	DPGDP ←→ DLE	3.0262***	5.1370***	7.8408***	22.040***	Yes
Solomon Islands	DPGDP←//→ DDLE	1.1725	2.0108**	2.552 ***	6.330**	Yes
Sri Lanka	DPGDP←//→ DDLE	–0.3915	–0.4414	–0.6655	34.540***	Yes
Tajikistan	DDPGDP → DLE	1.7240 **	2.9634 ***	3.8655***	0.245	No
Tanzania	DPGDP → DDLE	3.5212***	5.2002***	7.496 ***	117.01***	Yes
Tunisia	DPGDP←//→ DDLE	1.8795**	3.5226 ***	4.9534***	28.820***	Yes
Uzbekistan	DPGDP←//→ DDLE	4.3713***	5.5614***	5.3445***	11.630***	Yes
Vanuatu	DPGDP←//→ DDLE	0.8369	1.3834 *	1.7542 **	21.360***	Yes
Viet Nam	DPGDP → DLE	2.3568***	4.8640 ***	4.5275***	11.090***	Yes
Zambia	DPGDP←//→ DDLE	0.8553	1.9336**	3.2161***	83.450***	Yes
Zimbabwe	DPGDP←//→ DDLE	1.2202	1.9424 **	3.405 ***	2.242	No

LE causing PGDP is depicted by (←), PGDP causing LE is shown by, (→) Bidirectional causality between LE and PGDP is described by (green coloured ←→) and countries with No Causality between LE and PGDP is depicted by (red coloured ←//→)

Green shading indicates the presence of long-run cointegration (Yes), while red shading indicates no cointegration (No)

Unit root Tests: *MPPt* Modified Philips Peron test, *PPt* Philips Peron test, ADFt- Augmented Dickey-Fuller test. (Significance level at *10% **5% and ***1%)

even countries such as the Republic of Congo, Samoa, and Sri Lanka, which showed non-significant unit root effects, revealed evidence of long-term relationships. Johansen cointegration analysis also supports this trend for low-income countries, with 41 nations demonstrating systematic long-run correlations. As illustrated in Fig. 8, the countries marked in green represent those with confirmed long-run relationships between PGDP and LE, emphasising the broad applicability of this dynamic. These findings underscore the critical role of health, education, and infrastructure investments in fostering sustainable development and reinforcing the mutual benefits of health and EG over extended periods. This long-run coherence provides an empirical basis for SDG-aligned investments strengthening primary care and human capital while fostering productive, inclusive economies.

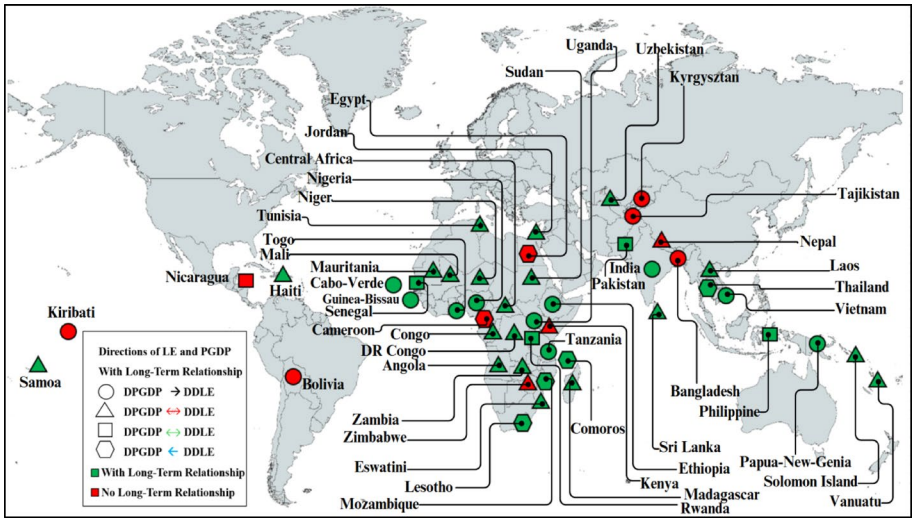

Fig. 8 Geographical Representation of Health Growth Linkages: Granger Causality and Cointegration Results *Source*: Authors' illustrations using a Map chart

4.3.3 Regional and income groups comparisons

Structural determinants and governance quality drive the link between LE and PGDP, and the study shows regional and income-based differences. While Bangladesh and India demonstrate unidirectional causation, lower-middle-income nations like Morocco and Nicaragua frequently have bidirectional correlations. Despite poor short-term ties, long-term equilibrium occurs in low-income areas. These dynamics are further influenced by structural problems such as inadequate infrastructure and governance problems, and ineffective policies, which emphasise the necessity of region-specific approaches to improve economic and health outcomes.

Of the 51 countries analysed, only 10 low-income nations exhibit this long-term relationship, accounting for less than 20%. Regional differences are evident, with African nations hinting at stronger and more stable relationships than their Asian and American counterparts, likely due to efforts to address health and economic challenges. These findings highlight the need for sustainable strategies targeting EG and public health to support development. The spatial patterning offers a practical roadmap for prioritising SDG interventions, focusing first on where long-run linkages are established and scaling enablers where gaps persist.

These findings advance the literature by demonstrating that while classical economic theory anticipates a health-led growth pathway, our evidence suggests this is not uniform across all low-income contexts. Instead, resilience is conditional on factors such as governance quality, healthcare access, and structural diversification, thereby challenging deterministic views of health economic relationships.

4.4 Comparative insights and anomalies

The comparative analysis reveals subtle relationships between PGDP and LE across income groups and periods. In low-income countries, a bidirectional relationship dominates, emphasising mutual influence. In contrast, lower-middle-income countries exhibit more diverse causal patterns, with some nations demonstrating a unidirectional or even no causal relationship. Pre-COVID periods generally highlight positive interdependence; however, post-COVID disruptions have introduced complexities, with some

countries experiencing a reversal of trends. Notably, disparities such as the absence of short-term causality in countries like Rwanda and Madagascar, or the non-significant unit root effects in countries such as Sri Lanka, suggest unique socio-economic or policy-driven dynamics. This emphasises the importance of tailored strategies in addressing the health-EG nexus. The resilience of Rwanda aligns with Iyakaremye et al. [23], who documented significant gains in LE following targeted health reforms. Our results extend the arguments of Preston [34] and Awoyemi et al. [7] by showing that income gains do not uniformly translate into health improvements without institutional support and diversified economies.

Taken together within the SDG framework, these comparative patterns argue for integrated, country-specific policy packages that synchronise health-system resilience (SDG 3) with inclusive employment and productivity agendas (SDG 8), rather than treating them as separate tracks.

5 Conclusion and recommendations

5.1 Summary of key findings

This study examines the relationship between LE and PGDP in low and lower-middle-income countries from 1990 to 2023, considering both the short and long term. The study finds that these two variables have a strong long-term relationship. In most of the countries studied, there is no evidence of short-term causality. Despite the absence of short-term causality, all low-income countries, including Central Africa, the Democratic Republic of Congo, Madagascar, Niger, and Sudan, display long-term balanced relationships. Conversely, countries such as the Philippines, Senegal, and Nicaragua exhibit bidirectional causality, emphasising the link between EG and LE. However, in over half of the countries examined, the lack of short-term causality suggests a need for targeted strategies to reduce health disparities and promote EG.

5.2 Contributions to knowledge

This study makes three key contributions to existing knowledge. First, it introduces long-term multi-country empirical analysis of the health economic nexus in the context of low and lower-middle-income countries, which is often neglected in prior research.

Second, by employing an integrated methodological framework (Wavelet, Granger, cointegration), it advances methodological practices in health economics and development studies, showing how time frequency approaches reveal hidden short-run disruptions alongside long-run equilibria.

Third, it challenges prevailing assumptions by demonstrating that EG alone is insufficient to guarantee improvements in LE, thereby reinforcing the centrality of healthcare investment and structural resilience in sustainable development pathways.

5.3 Policy implications

5.3.1 Short-term measures

In the short term, governments in low and lower-middle-income countries should priorities measures that directly addresses immediate health economic vulnerabilities highlighting by this study. Government fiscal health spending should be expanded, with the focus on community-based health care preventive services and mental and child health, as these directly improve workforce productivity and reduce avoidable mortality. Second,

pandemic preparedness must be strengthened through contingency health funds, strategic medical reserves, and real-time Surveillance systems that can detect shocks early and stabilise both health and economic outcomes. Third, digital health solutions such as telemedicine and mobile health platforms should be rapidly scaled through public–private partnerships to ensure access to care in underserved areas. Finally, targeted cash transfers and social safety nets can shield vulnerable households from pain deeper into poverty when a health crisis or economic contractions occur. Collectively, these measures provide governments with safeguarding in both human capital and economic stability in the immediate term. The long-term equilibrium observed is consistent with Rahman et al. [36] who demonstrated to positive impacts of healthcare expenditures on health outcomes SAARC Asian countries.

5.3.2 Long-term strategies

The long-run equilibrium between LE and EG identified in this study underscores the need for strategies that integrate health and economic resilience. Government should First, institutionalise joint health-economic planning by embedding SDG 3 and SDG 8 targets within national development frameworks. Second, countries must commit to allocating at least 5–6% of GDP to healthcare spending, prioritising preventive and primary services in line with WHO benchmarks. Third, economic diversification is critical: reliance on narrow economic bases (e.g., agriculture or tourism) leaves countries highly vulnerable to shocks, whereas investment in manufacturing, digital services, and green industries can create sustainable employment and resilience. Fourth, human capital formation should be accelerated through technical and vocational education aligned with healthcare, digital innovation, and public health management, creating a skills workforce development to strengthen the health-economic nexus. Finally, regional and international cooperation should be expanded to share resources, best practices, and innovations in crisis preparedness and recovery.

5.3.3 Recommendation for policy makers

Drawing on the empirical evidence and comparative analysis, five actionable recommendations are proposed for policymakers in low- and lower-middle-income countries.

1. Prioritise fiscal health spending by committing at least 5–6% of GDP to healthcare, with a strong focus on preventive and community-based services.
2. Establish institutionalised pandemic preparedness plans that integrate fiscal buffers, early warning systems, and cross-sectoral crisis coordination.
3. Accelerate economic diversification by fostering investment in manufacturing, digital innovation, and resilient service sectors to reduce vulnerability.
4. Develop national resilience indices to monitor health and economic preparedness, ensuring resources are directed to the most vulnerable regions and groups.
5. Strengthen South-South cooperation and international partnerships to enhance knowledge transfer, resource pooling, and alignment with global sustainable development agendas.

This finding directly informs Objective 4 by highlighting the need for context-specific policy responses: increasing fiscal health spending to address weak short-run linkages,

promoting diversification to reinforce long-term equilibria, and strengthening pandemic preparedness to mitigate future shocks.

5.4 Methodology constraints

The study employs Wavelet Coherence, Granger Causality, and Johansen Cointegration, but it may overlook non-linear interactions and feedback loops.

5.5 Data constraints

The analysis uses data from 1990 to 2023, limiting its scope and generalisability to higher-income groups or other contexts.

5.6 Contextual constraints

The analysis omits factors such as culture, governance, and policy, which play a vital role in influencing the relationship between LE and EG.

5.7 Recommendations for upcoming limitations

Future studies should broaden their scope to include a wider range of income groups, allowing for more generalisable findings. Comparative studies across diverse regions could reveal unique patterns in the relationship between LE and EG. Including variables such as cultural factors, governance quality, and policy differences would offer deeper insights into the complexities of this relationship. Broadening the analysis to cover more extended historical periods and future projections could aid in identifying long-term trends and shifts. Employing advanced methodologies and more comprehensive datasets may further elucidate the causal mechanisms linking health and economic progress.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s43621-025-02074-z.

Supplementary material appendix 1. Data file

Supplementary material appendix 2. Descriptive statistics

Supplementary material appendix 3. Granger results

Author contributions

All authors contributed to the conception and design of the project. RJ, DS and PL composed the writing of the manuscript. DS, PL, PN and LD carried out a significant share of tasks on statistical work in the manuscript. RJ and DS provided critical knowledge in drafting the paper and RJ supervised the entire study. The authors have read and approved the final manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

All the data utilised in the analysis is attached as a supplementary material Appendix 1.

Declarations

Ethics approval and consent for publication

Not applicable. This study used publicly available secondary data, and no direct involvement of human participants, human tissue, or identifiable personal data was required.

Consent to participate

Not Applicable.

Competing interests

The authors declare no competing interests.

Received: 4 August 2025 / Accepted: 7 October 2025

Published online: 12 November 2025

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