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Tanyaradzwa Njenje
University of Zimbabwe Business School
Senour Ahmadi
snour.ahmadi@unifg.it
University of Foggia https://orcid.org/0009-0005-8557-2706
Vito Amendolagine
University of Foggia https://orcid.org/0000-0002-5699-5233
Elisha Mavodyo
University of Zimbabwe Business School https://orcid.org/0000-0003-4133-5782
Albert Makochekana
University of Zimbabwe Business School

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The Energy–Environment–Health Nexus in Sub-Saharan Africa: Evidence from a Panel Fixed-Effects Analysis

Tanyaradzwa Njenje, University of Zimbabwe Business School, Zimbabwe
Senour Ahmadi, Department of Economics,University of Foggia, Italy. snour.agmadi@unifg.it (Correspondind author)
Vito Amendolagine, Department of Economics, University of Foggia, Italy.
Elisha Mavodyo, University of Zimbabwe Business School, Zimbabwe
Albert Makochekana University of Zimbabwe Business School, Zimbabwe

Abstract

This study analyzes the energy–environment–health nexus considering the relationship between renewable energy consumption and life expectancy in Sub-Saharan Africa. We use an unbalanced panel of 27 countries from 2000 to 2024. We fit a fixed-effects model with Driscoll–Kraay standard errors to assess heterogeneity, cross-sectional dependence, heteroskedasticity, and autocorrelation. Results indicate that life expectancy increases with greater consumption of renewable energy, even after controlling for GDP per capita, health expenditure, carbon emissions, and urbanization. Income, health expenditure, and urbanization improve health outcomes, evidenced by the positive coefficient on carbon emissions. Results reflect transitional development dynamics rather than a beneficial effect of pollution. findings indicate that the positive effect of renewable energy consumption increases health and welfare, in addition to being an environmental strategy. Thus, the study shows that the combination of increased renewable energy, improved health systems, and expanded clean energy access, is critical to achieving more inclusive and sustainable development in Sub-Saharan Africa.

Keywords:
renewable energy; life expectancy; energy–environment–health nexus; sub-saharan africa; panel fixed-effects model; sustainable development; health co-benefits

1. Introduction

The need to improve access to affordable and dependable energy sources is critical to the advancement of economic and energy policies in Sub-Saharan Africa. Many challenges face the region including severe energy poverty, an ever-increasing rate of urbanization, the persistence of health issues, and the high risks associated with climate change and the environment. Therefore, from

the perspective of energy policy, the issues of supply and decarbonization are secondary. In addition, energy policy deals with issues of social welfare, economic productivity, and health. An increasing number of studies in the field of environmental economics are looking into the negative effects of energy use and the resulting air pollution, the burden of disease and associated health care costs, and the long-term effects on human capital (Grossman, 1972; Landrigan et al., 2018; Markandya et al., 2018). In the case of low- and middle-income countries, the shift from use of polluting energy sources to clean energy sources may result in an improved environment and better health outcomes for the population.

The modern energy crisis affecting reliance on fossil fuels and traditional biomass is most pronounced in Sub-Saharan Africa. It is undeniable that reliance on diesel generation poses risks to health systems and household safety. This research illustrates that the Sub-Saharan region has the most significant electricity access deficit and highest dependence on polluting fuel sources as a result. This is a public health crisis as the region suffers the worst health impacts of poor energy and air quality. The implications of energy access go beyond household welfare; improves the operations of health facilities, vaccine cold chains, maternal and emergency services and the overall ability of the state to provide services. The policy implications in the energy sector go beyond the sector itself. Previous studies show that energy transitions have an impact on public health both directly and indirectly (Adair-Rohani et al., 2013; Smith et al., 2014; Shindell et al., 2022).

From a combined environmental and economic viewpoint, the adoption of renewable energy can be seen as an alteration of the social cost profile of energy use. If renewable energy sources improve the reliability of the electricity supply and also displace more polluting fuels, they may reduce the negative externalities associated with household and ambient air pollution, as well as the negative impacts of pollution on the productive efficiency of health systems. This reasoning supports the health capital model that describes the stock of health as influenced by the environment and other social investments (Alaebo et al., 2024;Grossman, 1972), as well as the energy-environment-health framework which highlights the complex relationships among energy systems, health, and economic development. Furthermore, it directly responds to integrated appraisal policy studies where the exclusion of health co-benefits from energy cost analyses of renewable energy systems leads to under-investment in such systems.

Although the concept is important the lack of practical evidence still pertains to Sub-Saharan Africa. International studies in general suggest that cleaner energy systems further develop health systems due to lower environmental degradation and a smaller population affected by pollution (Bhattacharya et al., 2017; Wang et al., 2023). However, the evidence is particularly thin and several reviewed articles show that many studies have small samples, smaller time spans, and lack focus on the African continent, and even less to Sub-Saharan Africa. Even fewer studies link the health effects of renewable energy to actionable cross-sector policy frameworks.

This study aims to determine the relationship between the adoption of renewable energy and the improvement of health in Sub-Saharan Africa. Therefore, the contribution is of two parts. First, it contributes region-specific evidence to the energy-health nexus by assessing the relationship between renewable energy and life expectancy in a multi-country Sub-Saharan African setting. Secondly, it addresses the empirical findings into policy frameworks that address the concerns raised in the article, such as cross-sectoral collaboration, health co-benefit analysis, decentralized health facility electrification, and clean cooking transitions.

1.1. Study purpose, objectives and research questions

The objective of this research study is to determine if there is a correlation between the adoption of renewable energy and improvement in the population health status in Sub-Saharan Africa. Furthermore, the study attempts to evaluate this correlation in regard to the wider energy–environment–health nexus. Specifically, the study assesses the impact of renewable energy consumption on the average life expectancy of a population while considering the level of a nation's economic development, health expenditure, total carbon emissions, and the rate of urbanization. This study attempts to cover the existing gap in literature on a comparative, multi-country analysis on the impact of adoption of renewable energy and the positive health outcome in Sub-Saharan Africa. In addition, this study attempts to fulfill the existing need for a model that links the objectives of the energy transition to positive health outcomes.

This article has three objectives that are interconnected. The first objective is to analyze the correlation between the consumption of renewable energy and life expectancy in Sub-Saharan Africa. The second is to find out if the correlation found in the first analysis is valid when considering other structural factors that determine health outcomes, namely, gross domestic product (GDP) per capita, health expenditure, total carbon emissions, and the level of urbanization. The third is to find out the implications of the first two objectives and to provide a model that proposes ways to adopt renewable energy in Sub-Saharan Africa that will result in positive health outcomes.

These objectives lead to the research questions: (1) What is the nature of the association between life expectancy and renewable energy consumption in Sub-Saharan Africa? (2) How do income, health-system expenditure, carbon emissions, and urban settlement differentials modify the association? and (3) What policies, and within what framework, can the identified renewable energy-health nexus be actualized in enhancing health of the people and expending energy systems in Sub-Saharan Africa?

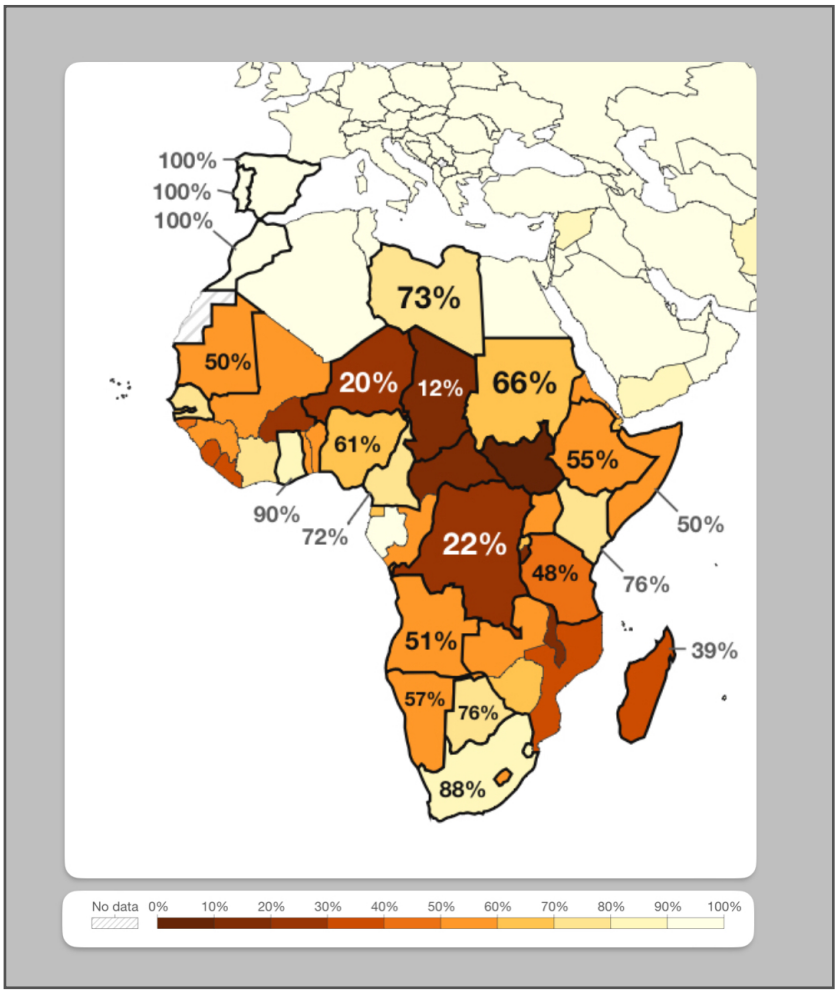
1.2. The State of Renewable Energy in Sub-Saharan Africa

Sub-Saharan Africa faces a profound energy inconsistency, as the region possesses some of the world's most abundant energy access. The figure 1 presents an overview of access to electricity in

African countries, showing that energy is not equally available across the continent. It shows that most of Sub-Saharan Africa still has much lower electrification rates, even though countries in North Africa and parts of Southern Africa have almost universal access. It has the lowest renewable energy adoption rates compared to any global region (Figure 2).

Solar irradiation levels are among the highest globally, with technical potential exceeding 10,000

Figure 1. Share of population of African countries in access to electricity



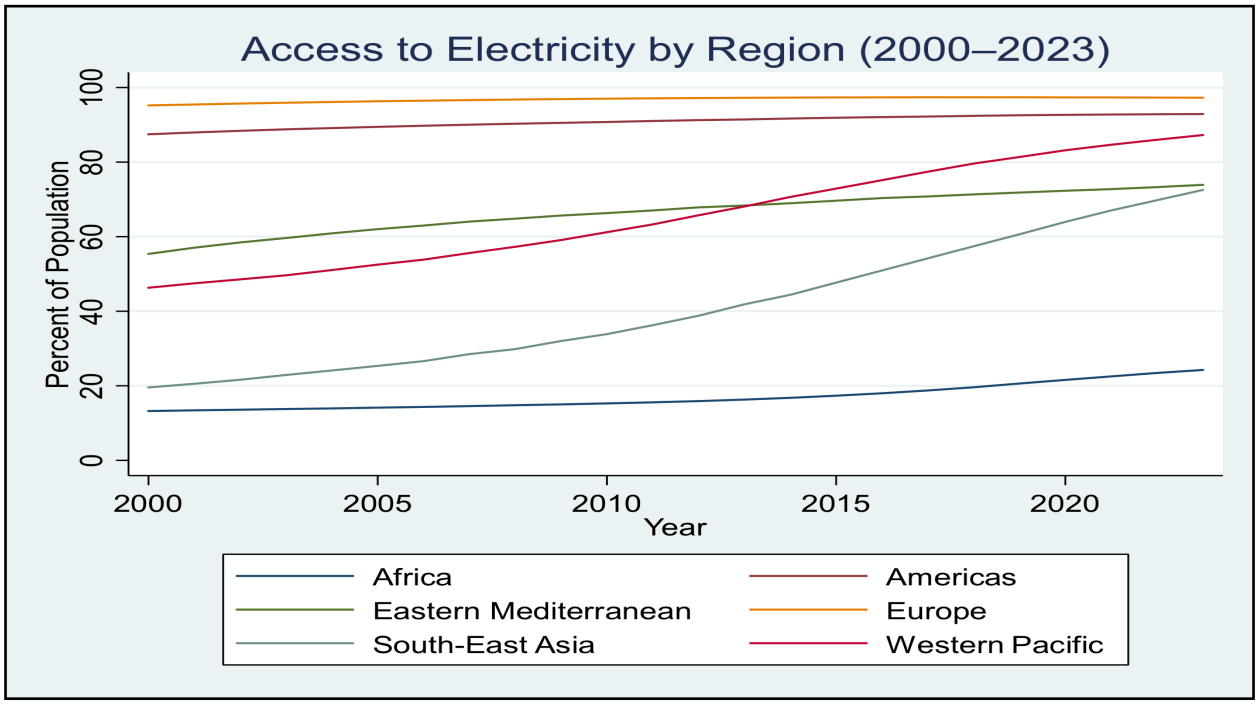
Data source: OurWorldinData.org/energy, 2023

GW (IRENA, 2024). Wind capacity is estimated at 100 GW and significant hydro and geothermal potential remains untapped (Boadu & Otoo, 2024). Despite this endowment, renewable energy constitutes a small fraction of the region's energy mix. Hydropower accounts for approximately 24%

of renewable electricity generation, while other renewable sources such as solar, wind and geothermal contribute only 5% combined (Byaro & Rwezaula, 2025a).

According to the World Bank (2025), more than 470 million people in Sub-Saharan Africa live with unreliable electricity access, while 171 million have no access at all. This energy deficit forces households and institutions to rely on highly polluting energy sources, with significant health consequences. Figure 2 illustrates Africa's position relative to other continents in electricity access from 2000 to 2023.

Figure 2. Access to Electricity by Region from 2000-2023



Source: World Health Organization (2025)

Figure 2 presents the estimated percentage of the population with access to electricity across six WHO regions from 2000 to 2023, illustrating a global effort to combat energy poverty. Globally, the trend is one of substantial progress. The African Region has seen steady, albeit slow, growth, increasing from 15% access in 2000 to only 20% in 2023 (WHO, 2025). This indicates that despite efforts, a vast majority of the population in this region still lacks electricity, highlighting a major developmental challenge. In contrast, the Eastern Mediterranean region demonstrated strong improvement, climbing from 55% to 76%, suggesting successful infrastructure investments. The

most dramatic transformation occurred in South-East Asia, which nearly tripled its access rate from 28% in 2000 to an impressive 70% by 2020, largely driven by massive national electrification campaigns in countries like India.

The Americas and Europe entered the century with already high access rates and successfully maintained or improved them, with Europe achieving near-universal access (99%) and the Americas holding steady in the mid-90s. The Western Pacific region presents a unique case; while it started at a high baseline of 88% in 2000 and peaked at 91% in 2010, it experienced a noticeable decline to 84% by 2020. This drop could be attributed to various factors, such as rapid population growth outpacing infrastructure expansion, data reporting changes, or specific disruptions in large countries within the region. Overall, the data reveals a world making significant strides toward universal electricity access, yet it also underscores the persistent and deep energy divide, particularly affecting sub-Saharan Africa.

2. Literature review, Theoretical foundation and conteptual framewrok.

This research utilizes the energy–environment–health nexus and provides a solid foundation for analyzing the impact of renewable energy on life expectancy in Sub-Saharan Africa. This perspective focuses on the health outcomes as a result of multiple interconnected energy systems, pollution, health services, and development, which is a departure from viewing them as influenced by one factor. This perspective allows us to extract the conceptual model from the literature and detail the channels through which renewable energy influences the health of the people.

A first strand of literature investigates the link between renewable energy and environmental improvement. In renewable energy studies, and the reduction of pollution and improvement of the environment. The range of positive outcomes will depend on the state of the institutions and level of development. Though, Bhattacharya et al. (2017) argue the degree of emissions reduction from the consumption of renewable energy is dependent on the economic and institutional environment. These sentiments are reflected in the reviews of Hanif (2018), Adeleye et al. (2022), and similar studies, all of which suggest the benefits from renewable energy adoption are not automatic. In the case of Sub-Saharan Africa, where the term renewable energy often includes harmful forms of biomass, the environmental impacts of the adoption of new forms of renewable energy may be negative, and in the case of Sub-Saharan Africa, the impacts may be even worse. As a result, literature is emphasizing the need to avoid assuming a simple cause and effect relationship between the adoption of renewable energy and pollution reduction.

A separate strand deals with pollution and its impact on health. Here, the evidence is more certain. Environmental epidemiology and health economics studies unambiguously show that morbidity and premature mortality, especially respiratory and cardiovascular, increase after exposure to ambient and household air pollution. The article rightly refers to Burnett et al. (2014) and Landrigan et al. (2018) and the other studies that document the serious health impacts of pollution and while household air pollution is particularly detrimental in poorer countries that use solid fuels. This literature provides the core externality-based justification for the health impact of energy transitions literature: energy systems that create pollution, as part of their operations, impose costs that are not captured in market prices, and these costs translate into a burden of disease, lost productivity, and premature death. Thus, from an environmental economics perspective, the health benefits of using cleaner energy are primarily a result of the reduction of emissions and the subsequent improvement of the environment.

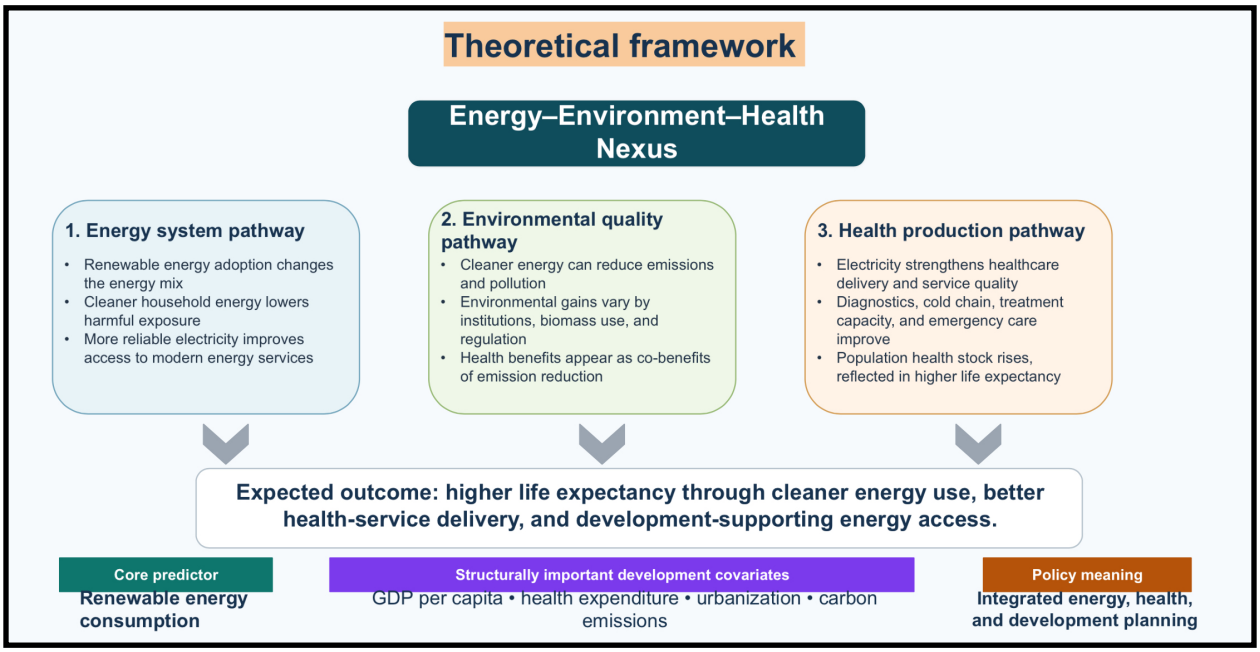
A third strand links renewable energy more directly to health outcomes. The existing literature is only disaggregating and reporting cleaner and renewable energy systems, and health including mortality and life expectancy. The literature is diverse in scope, methods, and causal reasoning. One of the studies that is most central to the positioning of the article Wang et al (2023) reports positive association of life expectancy and renewable energy consumption for a large cross country panel (via less carbon emissions). Similarly Alharthi and Hanif (2021) show that energy composition is important for health. The greater the reliance on fossil fuels in the energy mix, the greater the health risk, and the greater the reliance on cleaner energy, the better the health outcomes. In a country-specific case, Rahman and Alam (2022) support the same logic, while in the case of Europe, the evidence of (2021) Rodriguez-Alvarez supports the same where the investment in renewable energy is positive for health because of the environment. Collectively, the evidence suggests that energy transition is a health imperative in addition to being an environmental imperative.

The literature presents more other mechanisms in additiin to the improvement in the environment. Security in energy access can also support the systems and processes involved in the delivery of healthcare services. This includes the provision of services involved in the hospital equipments and patient care activities, and the provision of services involved in the emergency response. Adair-Rohani et al. (2013) show that the provision of healthcare services in African health facilities is limited by the absence of reliable electricity, thus illustrating one of the ways in which energy availability, or the lack of it, affects health. Adoption of renewable energy can lead to economic welfare benefits by providing the infrastructure necessary to modern energy, and facilitating the socioeconomic development of the area. Directly, the health benefits of renewable energy will come from less pollution and better healthcare delivery, while indirectly, there will be greater improvement in the health of the population.

There are some specific methodologies limitations for Sub-Saharan Africa. Studies rely on small sample shorts and select countries as well as mainly descriptive studies that do not capture cross-

country dependence and are heterogeneous. The contributions Adeleye et al. (2022), Hanif (2018), and Byaro and Rwezaula (2025) have made are significant, but still the understanding the robustness, the scope, the mechanisms and the channels pertaining to the renewable energy-health nexus is limited. For instance, Byaro and Rwezaula (2025) do detect positive health impacts, but machine learning analyses do not provide an equivalent level of evidence as panel, theory driven, confirmation methodologies. Thus, this clearly points to the absence of an evident theory and conceptual framework in the S-Saharan Africa literature to analyze the impact of renewable energy on health.

Figure3. Theoretical framework of the study based on the energy-environment-health nexus



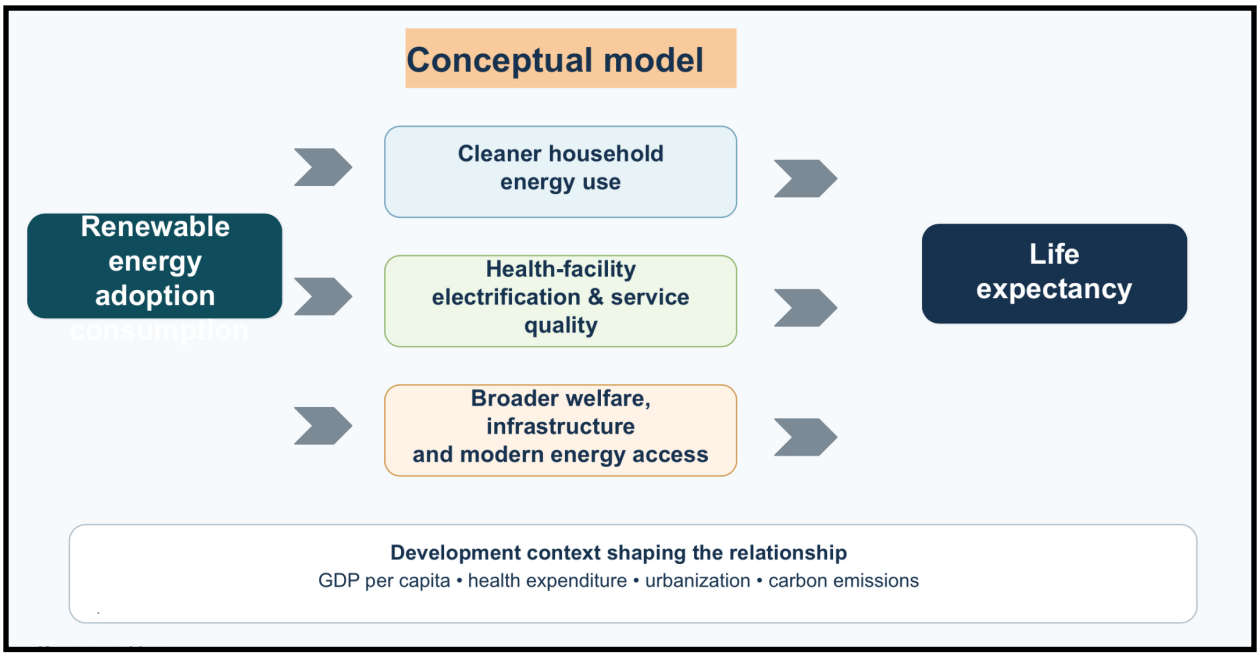
Source:Authors' elaboration

The study's theoretical framework, illustrated in Figure 3, is set against this background. The framework is based on the energy-environment-health nexus and identifies three broad pathways through which renewable energy can influence life expectancy. The initial pathway is energy system, which proposes that the adoption of renewable energy transforms the energy mix, encourages cleaner household energy use, and broadens the reach of dependable electricity and modern energy services. The next is environmental quality pathway, which stems from the fact that cleaner energy can lead to lower emissions and less pollution, though the magnitude of the benefits is contingent on the institutional framework, level of dependency on biomass, and the stringency of regulations. The final pathway is health production, which postulates that better availability of electricity improves the overall quality of health care through the strengthening of the diagnostic systems, cold-chain

treatment systems, and emergency care. It is expected that through the use of cleaner energy systems, improved population health will lead to increased life expectancy.

Figure 3 illustrates the conceptual model that has been derived from the aforementioned proposed theories. This model specifies how the adoption of renewable energy has the potential to increase life expectancy through three channels: providing cleaner energy for use in the household, electrification of health facilities and improvement in the quality of the services provided, and the broad welfare, infrastructure, and provision of modern energy. This model is based on the literature summarized above and not on the basis of any empirical evidence. The cleaner household energy channel is based on evidence that shows the adverse health effects associated with high levels of pollution. The health facility channel is based on evidence that demonstrates how the availability of reliable electricity improves the provision of health care and the quality of services. The broad welfare and infrastructure channel is based on the role of modern energy in supporting development, which improves the overall living standards, accessibility of various services, and the well-being of the population. The conceptual model therefore illustrates the key mechanisms identified in the literature on how

Figure 4. Conceptual model of study for the correlation between the adoption of renewable



Source: Authors' elaboration

renewable energy can affect the life expectancy of people in Sub-Saharan Africa.

Figure 2 illustrates a conceptual model that derives directly from these theorical premises. It shows that renewable energy adoption is predicted to increase life expectancy through three channels:

cleaner energy use in households, better electrification and service upgrades in health facilities, and wider modern energy and infrastructure access and balance. Unlike models formulated from empirical results, this conceptual model is based on the literature described above. The cleaner household energy channel illustrates the link between the removal of pollutants, and the improved health of the population. The health-facility channel is based on the findings that the presence of electricity improves the provision of healthcare and the quality of services. The wider welfare and infrastructure channel is based on the modern energy nexus that supports the development of systems that improve infrastructure, services, and the overall welfare of the population. Thus, the conceptual model describes the key mechanisms in the literature that renewable energy may increase life expectancy in Sub-Saharan Africa.

In this set of data, GDP, healthcare expenditures, urbanization, and carbon emissions will be treated as structurally significant covariates, as opposed to peripheral controls. GDP reflects the overall level of development and the vortex of resources that can be channeled to optimize the standard of living and health. Health expenditure captures the ability of the health system to convert improvements in the health-related supporting infrastructure and energy, to the health status of the population. Urbanization reflects the structural changes that can result in an improved access to the upgraded system of services, accompanied by an ecosystem of economic opportunities and related environmental and congestion pressures. Finally, carbon emissions relate to the degradation of the environment through the energy system that channels the effect on health. All of these variables determine the context in which renewable energy resources are located and the extent to which they can be used to positively affect life expectancy.

The literature, theoretical framework, and conceptual model together support the assertion that the adoption of renewable energy in Sub-Saharan Africa is expected to lead to increased life expectancy, although the size and even the sign of the effect are conditioned by the particular institutional, geo-biophysical, and socio-economic development context. Therefore, renewable energy should not be viewed merely as a replacement for fossil energy, but as enabling a more fundamental socio-economic development paradigm shift that positively affects all of the environmental, healthcare, and public health systems.

3.Methodology

This research uses a comparative panel-data methodology to analyze the relationship between renewable energy and the health of a population, specifically focusing on Sub-Saharan Africa. The study examines an unbalanced panel of 27 countries in Sub-Saharan Africa and employs a country

fixed effects model with Driscoll-Kraay standard errors for the years 2000-2024. This is a macro-panel study with a specific set of guidelines, making it the most appropriate for this study.

The empirical model is based on the energy-environment-health nexus described in previous sections of this study. This approach suggests that population health is determined by factors beyond the healthcare system and income levels, including environmental quality and energy system adequacy. The study considers renewable energy consumption as the primary explanatory variable of interest. In contrast, the other variables, such as GDP per capita, health expenditure, carbon emissions, and urbanization, while still important, can be viewed as control variables for the developmental framework that shapes health outcomes of the population.

Accordingly, the empirical model is specified as follows:

$$lnLE_{it} = \mathscr{B}_0 + \mathscr{B}_1 lnREC_{it} + \mathscr{B}_2 lnGDPpc_{it} + \mathscr{B}_3 lnHE_{it} + \mathscr{B}_4 lnCE_{it} + \mathscr{B}_5 lnURB_{it} + \mathscr{u}_i + \lambda_i + \varepsilon_i$$

Where: LE represents Life Expectancy , REC represents Renewable Energy Consumption, GDPpc is gross domestic product per capita at time *t,* HE denotes Health Expenditure, CE reflects the level of Carbon Emissions at time t, URB represents percentage of population living in urban areas, $\mathscr{u}$ represents national fixed effects, controlling for individual difference factors that do not change with time, λ represents time fixed effects, controlling for factors that do not change with country, ϵ_{it}Is the white noise error term capturing all omitted variables that influence healthcare service delivery but are not explicitly included in the model.

The estimating equation involves variables such as life expectancy, renewable energy consumption, Gross domestic product per capita, health expenditure, carbon emissions, and urbanization. The term unobserved country-specific effects that are fixed over time and is the idiosyncratic error term.

The log-log specification has two main advantages for this study. Firstly, it makes it easier to study policy impact simulations, as it allows for the estimation of the coefficients as elasticities. Secondly, for any given sample, the log transformation of the dependent and independent variables makes it possible to reduce the effect of extreme values and the effect of heteroskedasticity, as well as diminish the effect of extreme values of the variables for each given sample. In the case of this study, the coefficient for renewable energy consumption refers to the marginal effect of the percentage change of the life expectancy of the population due to a 1% increase in the consumption of renewable energy, ceteris paribus.

3.1. Variable definition and measurement

The dependent variable is life expectancy at birth, taken in natural logarithm. Life expectancy is a common indicator in global health and development research, as it captures the totality of mortality experience of a population, and integrates the effects of disease burden and the underlying socioeconomic, environmental, and healthcare system determinants. Given the focus of this paper, it is an ideal indicator of population health as it is broad and captures the effects of various determinants instead of focusing on the burden of a specific disease.

Renewable energy consumption is the main independent variable, and is measured as the proportion of renewable energy in total final energy consumption. It is measured in natural logarithm. The variable measures the extent of dependence on renewable energy sources in national energy systems. It is assumed within the study's framework that the greater the consumption of renewable energy, the better the health of the population. This is due to several reasons, including the greater population reliance on cleaner energy sources, and better energy systems that support greater economic development and other positive societal effects.

We include GDP per capita to account for the varying economic developments throughout the world over time. Higher levels of income usually mean better nutrition, sanitation, healthcare, and public systems, all of which is correlated with life expectancy. We include health expenditure as an indicator because the financing of health care services determines the availability of health care personnel and infrastructures, and the health system’s ability to prevent and cure diseases. We use carbon emissions as a proxy for the environmental burden of fossil fuel-based development, and we include urbanization as a proxy for the structural transformation and agglomeration effects, and the varying levels of accessibility to health-related services and infrastructure.

The preferred estimator is the fixed-effects model with Driscoll–Kraay standard errors. The use of fixed effects is motivated by the likelihood that unobserved country characteristics, such as institutional quality, historical health-system capacity, regulatory traditions, geography, or long-run development patterns, are correlated with both renewable energy adoption and health outcomes. Under such conditions, random-effects estimation would be inappropriate because it assumes no correlation between the regressors and the unobserved country-specific effect. The fixed-effects estimator addresses this problem by removing time-invariant heterogeneity and identifying the relationship of interest from within-country variation over time.

3.2. Data sources and sample

The study relies on secondary data drawn from internationally recognized databases, principally the World Bank’s World Development Indicators and the World Health Organization, in order to maximize cross-country comparability and consistency over time . The final dataset is an unbalanced panel covering 27 Sub-Saharan African countries from 2000 to 2024. The unbalanced nature of the panel reflects differences in data availability across indicators and countries, which is common in

African macro-comparative research and does not invalidate fixed-effects estimation provided that missingness is not systematically related to the model error term.

The effective estimation sample for the preferred model is 577 observations, as reported in the final regression table. The use of a multi-country African panel improves on single-country or short-panel studies by enabling the analysis to exploit both cross-country and within-country variation while remaining focused on a region that is often underrepresented in the international evidence base.

4. Results

This section presents the empirical results of the study examining the relationship between renewable energy adoption and health outcomes in Sub-Saharan Africa. Using unbalanced panel data from 27 Sub-Saharan African countries from 2000 to 2024. The study employs life expectancy at birth as the dependent variable and renewable energy consumption as the main explanatory variable, while controlling for GDP per capita, health expenditure, carbon emissions and urbanization. The estimation strategy follows the methodological framework outlined in Chapter Three, guided by the Grossman Health Capital Model, the Environmental Kuznets Curve hypothesis, the Production Function Theory and the Energy-Environment-Health Nexus framework.

4.1. Descriptive statistics

The descriptive statistics reveal that Sub-Saharan Africa exhibits substantial heterogeneity across all indicators, reflecting the diverse economic, demographic, and energy landscapes of the region. Life expectancy has an average of approximately 58.5 years), ranging from a low of 42 years to a high of 74 years, highlighting significant health disparities across countries. Renewable energy consumption averages 27.7% of total energy use but varies dramatically from minimum 0.2623643 (1.3%) to nmaximum 4.60517 (100%), indicating that while some countries have achieved near-complete reliance on renewables, others remain heavily dependent on fossil fuels and traditional biomass (Table 1).

Table 1-Descriptive Statistics

variable	mean	Median	sd	min	max	N
In_le	4.066585	4.085331	0.1105288	3.746979	4.306199	594
Income (log) (ln_rec)	3.323101	3.496508	0.8456536	0.2623643	4.60517	641
GDP per capita (log) (ln_gdppc)	6.884632	6.721174	1.033242	4.696781	9.809756	675

Table 1-Descriptive Statistics

variable	mean	Median	sd	min	max	N
Health expenditure (log) (ln_he)	1.470915	1.454102	0.4339283	0.1018339	3.089672	611
CO_2 emissions (log) (ln_ce)	1.424521	1.603782	1.350152	-1.905152	4.882121	675
Urbanization rate (log) (ln_urb)	3.551988	3.626182	0.4755866	2.084903	4.523	675

GDP per capita averages approximately $978, with a wide range from $110 to $18,230, reflecting the broad spectrum of economic development from low-income to upper-middle-income countries. Health expenditure averages $4.35 per capita, with notable variability indicating differences in national health priorities and fiscal capacity. Carbon emissions average 4.16 metric tons per capita, ranging from very low levels in primarily agrarian economies to high levels in fossil-fuel-producing nations, while urbanization averages 3.551988 (34.9%), capturing the ongoing structural transformation from predominantly rural to increasingly urbanized societies. These descriptive patterns provide important context for the subsequent econometric analysis, underscoring the need to account for the considerable cross-country heterogeneity characterizing Sub-Saharan Africa.

4.2. Correlation Analysis

Table 2 presents the pairwise correlation matrix for all variables used in the analysis. Life expectancy exhibits a positive and statistically significant correlation with renewable energy consumption (0.5581), GDP per capita (0.4330) and Carbon emissions (0.4259). This is consistent with theoretical expectations that economic development and improved energy infrastructure are associated with better health outcomes. The positive correlation with urbanization (0.2073) is also in the expected direction, though relatively weak. Health expenditure exhibits a weak negative correlation with life expectancy (-0.0264). The correlations of variables are under 0.7, indicating that multicollinearity is unlikely to pose a concern for the multivariate analysis that follows.

Table 2- Correlation matrix

Variable	ln_le	ln_rec	ln_gdppc	ln_he	ln_ce	ln_urb
ln_le	1.0000					
ln_rec	0.5589	1.0000				
ln_gdppc	0.4321	0.6992	1.0000			
ln_he	-0.0280	-0.3635	-0.3179	1.0000		
ln_ce	0.4275	0.6344	0.4424	-0.3804	1.0000	
ln_urb	0.2048	0.6814	0.6368	-0.4515	0.4314	1.0000

4.3. Panel unit root test]

Table 3 presents the Fisher-ADF test results for the natural logarithmic transformations of all six variables. The results reveal a mixed order of integration across the variables. Life expectancy and urbanization are stationary at levels, as evidenced by p-values of 0.000 and 0.0001, respectively, indicating they are integrated of order zero, I(0). Conversely, renewable energy consumption, health expenditure, GDP per capita and carbon emissions exhibit unit roots at levels, with p-values of 1.000, 0.1163, 0.6166, and 0.9993, respectively. However, after first differencing, all four variables become stationary at the 1% significance level ($p = 0.000$), indicating they are integrated of order one, I(1).

Table 3-Panel Unit Root Test Results

Variable	Fisher-ADF (Levels)	Fisher-ADF (First Diff.)	Order of integration	Level of Stationary
ln_le	0.000	-	1(0)	Levels
ln_rec	1.000	0.0000	1(1)	First difference
ln_he	0.1163	0.0000	1(1)	First difference
ln_gdppc	0.6166	0.0000	1(1)	First difference
ln_CE	0.9993	0.0000	1(1)	First difference
ln_urb	0.0001	-	1(0)	Levels

4.4. Cross-sectional dependence test

The Pesaran CD test was employed to detect cross-sectional dependence across the 27 countries in the sample. The results, presented in Table 4, reveal strong evidence of cross-sectional dependence for all variables at the 1% significance level. Life expectancy exhibits the highest degree of cross-sectional dependence (CD = 82.89, correlation = 0.943), followed by renewable energy consumption (CD = 76.29, correlation = 0.871), GDP per capita (CD = 75.77, correlation = 0.809), urbanization (CD = 69.10, correlation = 0.794), and carbon emissions (CD = 50.95, correlation = 0.567). These findings suggest that macroeconomic, demographic, and energy-related conditions are highly synchronized across countries, reflecting the influence of global business cycles, trade integration and shared development trajectories.

In contrast, health expenditure exhibits the weakest cross-sectional dependence (CD = 8.67, correlation = 0.095), suggesting that health spending decisions are primarily shaped by country-specific factors such as domestic policy choices, fiscal capacity, and institutional frameworks rather than global forces. Carbon emissions occupy an intermediate position, indicating that while emissions are influenced by global energy markets and climate policies, they remain closely tied to country-specific industrial structures and development pathways. The presence of cross-sectional dependence across all variables necessitates the use of estimation methods robust to this phenomenon.

Accordingly, the Driscoll–Kraay (1998) standard errors are employed in the main regression analysis to ensure valid inference.

Table 4-Cross-Sectional dependence test results

Variable	CD Test Statistic	p-value	Correlation
In_le	82.89	0.000	0.943
In_rec	76.29	0.000	0.871
In_gdppc	75.77	0.000	0.809
In_he	8.67	0.000	0.095
In_ce	50.95	0.000	0.567
In_urb	69.10	0.000	0.794

4.5.Multicollinearity test

The Variance Inflation Factor (VIF) was employed to detect the presence of multicollinearity among the explanatory variables. As shown in Table 5, all VIF values are well below the conventional threshold of 10, ranging from 1.33 for health expenditure to 3.08 for renewable energy consumption. The mean VIF is 2.12, which is substantially lower than the critical threshold of 5. These results confirm that multicollinearity does not pose a concern in this analysis. The relatively higher VIF for renewable energy consumption (3.08) is expected, given its theoretical correlation with GDP per capita and urbanization. Countries with higher income levels and greater urban development tend to have higher renewable energy investments. However, this level remains well within acceptable limits and does not threaten the stability of the coefficient estimates. The low VIF values indicate that each explanatory variable captures distinct dimensions of the energy-health nexus without excessive overlap, ensuring that the estimated coefficients from the subsequent regression analysis can be interpreted as reflecting the marginal effects of each variable with stable and reliable standard errors.

Table 5- Variance Inflation Factor (VIF)

Variable	VIF	1/VIF
In_rec	3.08	0.324780
In_urb	2.25	0.444167
In_gdppc	2.16	0.463101
In_ce	1.76	0.568995
In_he	1.33	0.752532
Mean VIF	2.12	

The modified Wald test for groupwise heteroskedasticity yields a test statistic of 4382.24 with a p-value of 0.000, strongly rejecting the null hypothesis of homoskedasticity. This indicates that the variance of the error terms differs significantly across Sub-Saharan African countries, reflecting the substantial heterogeneity in economic structures, energy systems, institutional quality, and health outcomes across the region. Countries at different stages of development, ranging from low-income agrarian economies to middle-income industrialized nations, exhibit fundamentally different error structures that cannot be assumed constant. To test for serial correlation in the panel data, the Wooldridge (2002) test for first-order autocorrelation was employed. This test is specifically designed for fixed effects models and is robust to heteroscedasticity.

4.6. The Heteroskedasticity and Autocorrelation Testing

The modified Wald test for groupwise heteroskedasticity yields a test statistic of 4382.24 with a p-value of 0.000, strongly rejecting the null hypothesis of homoskedasticity. This indicates that the variance of the error terms differs significantly across Sub-Saharan African countries, reflecting the substantial heterogeneity in economic structures, energy systems, institutional quality, and health outcomes across the region. Countries at different stages of development, ranging from low-income agrarian economies to middle-income industrialized nations, exhibit fundamentally different error structures that cannot be assumed constant. To test for serial correlation in the panel data, the

Wooldridge (2002) test for first-order autocorrelation was employed. This test is specifically designed for fixed effects models and is robust to heteroscedasticity.

Table 6-Heteroskedasticity and Autocorrelation testing

Test	Test Statistic	p-value
Modified Wald Test (Heteroskedasticity)	4382.24	0.000
Wooldridge Test (Autocorrelation)	12.238	0.0017

Table 6 summarizes the modified Wald test for groupwise heteroskedasticity and the Wooldridge test for first-order autocorrelation.This means that for valid inferences, conventional fixed effects with default standard errors will not suffice. Along with earlier evidence of cross sectional dependence, the diagnostics provide further justification for implementing fixed effects with Driscoll-Kraay standard errors due to heteroskedasticity, autocorrelation, and cross sectional dependence in macro panel data.

4.8. Post Estimation results

Results after estimation show that the preferred specification is performing quite well. The fixed effects model is validated by the F-test result and the within model explanatory power is quite strong at an R-squared = 0.7189 . The result of the multicollinearity test is still acceptable, and the Ramsey RESET test shows no evidence of misspecification of the functional form or omitted variable problems that are larger than the model at this scope of estimation (Table 7)

Table 7- post-estimation results

Test	Test Statistics	Status
F-Test for FE	0.0000	passed
R-squared	0.7189	Good Fit
Mean VIF	2.02	No Multicollinearity
Ramsey RESET test	1.56	No Omitted Variables

All diagnostics collectively augment internal model consistency and provide additional confidence to the ensuing regression results. While these diagnostics do not completely eliminate identification

concerns, they do provide some level of empirical coherence to the model, thus, the model is adequate for explaining the within-country relationships.

4.9. Cross Sectional Dependence and Model Selection: Fixed Effects, Random Effects, System GMM/Y Model

The Driscoll-Kraay standard errors with fixed effects is posited to be the best estimator after the diagnostic checks. This is parallel to both the theoretical framework of the study and the statistical behavior of the data. The Hausman test was employed to determine the robustness of the random effects estimator. The results of the Hausman test are found in Table 8.

Table 8-Hausman test results

Test	Chi-square Statistics	Degrees of freedom	p-value
Hausman Test	17.85	5	0.0031

The Hausman test null hypothesis posits that the random effects estimator is both consistent and efficient (Table 8). The null hypothesis is disqualified with the p value of 0.0031, suggesting that the unobserved country-specific effects are associated with the regressors. This is, indeed, plausible as time-invariant national characteristics like institutional quality, geography, regulatory traditions, and long-term health-system capacity have the tendency to affect both the adoption of renewable energy and the life expectancy. Given these attributes, the fixed effects estimator is the most suitable, for it eliminates time-invariant effects and delivers consistent estimates derived from within-country variations over time.

System GMM was also evaluated due to its importance in estimating dynamic panels. In this case, though, it was not kept as the primary option. In the case of the draft results, a number of the system GMM estimates did not meet the critical requirements of the necessary inferential framework. More specifically, the Arellano-Bond second-order serial correlation test returned a statistically significant result, raising validity concerns for the instruments. The test also had a pretty large, and rather, Hansen p-value suggesting, at least, instrument proliferation and reduced test reliability.

The most significant reason for this, though, is that preferred empirical models do not typically center around a dynamic framework whose primary focus is a lagged dependent variable. In this case, it is primarily to determine the relationship between renewable energy consumption and life expectancy, taking into consideration the unobserved heterogeneity and the complicated nature of the error. In this regard, fixed effects with the Driscoll-Kraay standard errors offer a framework that is sufficiently aligned with the model, and is also easier to interpret, given the study's design and the available evidence.

4.10. Results of Fixed Effects Regression

Estimates from the fixed effects model suggest that there is a positive and statistically significant association between consumption of renewable energy and life expectancy. The model estimates the effect of renewable energy consumption at 0.0257541, significant at the 1% level. This means that, ceteris paribus, a 1% increase in renewable energy consumption is associated with 0.026% increase in life expectancy. This finding confirms the central hypothesis of the study that more and better energy will yield more and better health benefits in the energy–environment–health framework (Table 9)

Table 9-Fixed Effects Regression with Driscoll-Kraay standard errors

Variable	Coef	Drisc-Kraay Std. Err.	t-Statistics	Prob
ln_rec	0.0257541	0.0063434	4.06	0.001
ln_he	0.0295709	0.0041012	13.19	0.000
ln_gdppc	0.0541039	0.0043418	6.81	0.000
ln_ce	0.0349946	0.005158	6.78	0.000
ln_urb	0.1323881	0.0131266	10.09	0.000
Constant	3.057564	0.0332916	91.84	0.000
Observations	577			
R-	0.7189			
Countries	27			

Other explanatory variables also positively and statistically significantly affect life expectancy. Health expenditure is recorded at a coefficient of 0.0295709, suggesting that the more investments there are in the health sector, the better the health outcomes will be. The coefficient of the GDP per capita is recorded at 0.0541039, indicating that economic development is of greater significance in predicting life expectancy. In the model estimated, positive association of life expectancy is recorded with the carbon emissions, with a coefficient of 0.0349946, while urbanization has the greatest coefficient of 0.1323881, showing a better relationship with health outcomes in the study.

4.11. System GMM Regression Findings

As System GMM estimates consider the dynamics of life expectancy, and specific nature of its persistence, they further enhance the effects of what these estimates show. The effect of the lagged dependent variable is positive and highly significant, suggesting stronger life expectancy persistence;

improvements in health outcome from the past, pull the present health outcomes upwards. This is consistent with the overarching analysis of the study, which is framed from the perspective of health outcomes evolving cumulatively, rather than in the instantaneous sense. The positive and statistically significant effect of life expectancy from consumption of renewable energy is consistent with the primary finding of the study, which asserts that the availability of clean and dependable energy service is associated with better health of the population. This effect, though small, is robust even after controlling for endogeneity and dynamic adjustment. This lends further confidence to the primary findings of fixed effects model (Table 11) .

Table 11. System GMM regression results

ln_le	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
L	.76	.054	14.09	0	.654	.866	***
ln_rec	.014	.006	2.23	.026	.002	.026	**
ln_gdppc	.007	.004	1.51	.131	-.002	.016	
ln_he	.011	.007	1.55	.12	-.003	.025	
ln_co2	.004	.003	1.30	.193	-.002	.009	
ln_urb	-.022	.011	-1.99	.046	-.043	0	**
Constant	.947	.198	4.78	0	.559	1.335	***
Mean dependent var		4.076	SD dependent var			0.104	
Number of obs		552	Chi-square			4572181.465	

*** p<.01, ** p<.05, * p<.1

Other control variables such as GDP per capita, health expenditure, and carbon emissions, within the GMM framework, do not show the existence of short-run dynamic impacts when persistence and endogeneity are accounted for. The case of urbanization shows a weakly significant negative correlation, probably reflecting the impacts of short-run congestion on the infrastructure and the public health system of the fast urbanizing areas. The insights provided are useful, despite the System GMM results limitations, particularly the concerns regarding the validity of the instruments and the presence of serial correlation, that call for the results to be taken with a degree of caution. The significant coefficient of renewable energy across the various estimation techniques lends weight to

the conclusion of the study, that renewable energy is critical to improving life expectancy in consideration of the energy, environment, and health interlinkages.

In previous sections, we examined the conceptual framework for interpreting the positive coefficient on renewable energy consumption. Although the result does not suggest a narrow technological impact, it does suggest that renewable energy is a component of a broader system of economically beneficial changes, which includes cleaner energy, better infrastructure, more reliable services, and reduced environmental hazards. The significance of positive per capita GDP, health spending, carbon emissions, and urbanization further supports the author's core argument that the positive health outcomes of a population result from multiple, interrelated environmental, economic, and social determinants, rather than one isolated factor.

The positive coefficient on carbon emissions is a potential cause for concern. In this particular sample, emissions could reflect the burgeoning growth and industrialization that coincides with improved energy access, infrastructure, and services. Therefore, the coefficient should not be interpreted as support for the notion that higher emissions have health benefits. In this context, emissions may be associated with the types of development that contribute to increased life expectancy. This is a more accurate interpretation of the framing of the manuscript than a purely mechanical approach to the coefficient.

The model explains a large proportion of life expectancy variation within countries, demonstrated by within R-squared = 0.7189. The results give empirical backing to the case that in the case of Sub-Saharan Africa, the consumption of renewable energy is both an environmental indicator and a policy relevant indicator of the health of the population.

5. Discussion

This study analyzed the impact of renewable energy on life expectancy in Sub-Saharan Africa and the impact of several structural determinants of health on this relationship. Additionally, the study seeks to answer the policy impact of the findings. The results provide answers to the first two research questions. In the preferred fixed-effects model, there is a positive and significant relationship between life expectancy and renewable energy consumption, and this relationship holds when health expenditure, GDP per capita, carbon emissions, and urbanization are controlled. This means that renewable energy in Sub-Saharan Africa holds a unique place in the energy–environment–health framework and should be regarded as a health and welfare enhancing resource in the region.

The first research question helps clarify the relationship of both variables as positive, which indicates that the more the region depends on renewable energy, the greater the life expectancy in that region. This shows that the benefits of the renewable energy transition in sub-Saharan Africa go beyond climate mitigation and energy diversification. In African economies with energy poverty, unreliable energy supply, and dependence on dirty fuels, renewable energy can improve health by

reducing exposure to dangerous pollutants, providing reliable electricity to households as well as health care facilities, and supporting productive activities that improve the overall welfare. Such improvements are expected to be witnessed in the region after the adoption of renewable energy. This understanding resonates with the global and regional studies that show the relationship of renewable energy and improved health, including increased life expectancy, especially under conditions when renewable energy changes the context in which health is produced (Wang et al., 2023; Beyene & Kotosz, 2021). This is also the case with the recent studies that show a positive relationship in Africa and other regions of the world between renewable energy and health improvements or reduced mortality (Byaro & Rwezaula, 2025; Hlongwane & Khobai, 2025; Singh et al., 2025).

The results contribute to the emerging African literature that energizes the debate on separating energy and health policies. In Sub-Saharan Africa, the energy-health nexus is influenced by insufficient and fragmented infrastructure, with a mix of modern and traditional energy systems. In such scenarios, renewable energy can improve health not only by lowering ambient emissions, but also by providing a modern energy service to households, health facilities, and communities. This explains the significance of renewable energy even after controlling for the level of income and government expenditures. The finding adds to Adeleye et al.(2022) who established the relationships among carbon emissions, renewable energy, income, and mortality in Sub-Saharan Africa. It goes further and renews the argument that, in a macro-panel context, renewable energy has a unique contribution to life expectancy. It further supports Osakede et al.(2025), who posited that renewable energy can limit the mortality burden of Africa's carbon footprint, and also fits the findings of Warsame (2023), which showed that, in Africa, renewable energy and the state of the environment together determine life expectancy.

Addressing the second research question, it was ascertained that the relationship from renewable energy sources to life expectancy continues even when the structural determinants of health are controlled for. It was established that GDP per capita and health expenditure are positively correlated with life expectancy. This confirms that the health of the population in the developing regions of the world depends, in addition to the environmental conditions, to the economic and health system providing services, and also to the health system. Thus, it seems that renewable energy acts as a structural determinant of health in the developing regions of the world, but not as a singular one. The positive impacts of renewable energy are likely to be greater when households are of higher income, the government is spending more money on health, and the country is able to use energy access in a more effective manner. This concurs with Wang et al. (2023) who identify a positive relationship between renewable energy, economic development, and life expectancy, and with Uzoechina et al. (2024) who argue that the use of energy for health in West Africa is highly contextualized in relation to other developing contexts. It also speaks to Ibrahim et al (2021) and Ibrahim et al (2022) who

argue that the health and economic development of Africa and The Sub Saharan Region depends on the type of energy, the technology employed and the overall structural conditions.

The African energy-health nexus is heterogeneous. The positive renewable energy coefficient does not mean that all renewable energy sources are health improving, or that all countries enjoy health improvements from renewable energy. In Sub-Saharan Africa, renewable energy sources may include traditional biomass, which is renewable, but when used in a polluting and inefficient manner, traditional biomass is detrimental to health. The result of the policy analysis does not mean that more renewable energy is better, but rather, that the shift to clean, safe and modern renewable energy systems is a result of better health. This explains the more complex and asymmetric results in previous studies. Somoye et al. (2024) show asymmetric health impacts of fossil fuels and renewables in Nigeria. Ibrahim et al. (2021) showed that non-renewable energy may, paradoxically, lead to a short-term improvement in the quality of life during the energy access and development phase. Therefore, the findings must be interpreted from the context of showing a positive association for renewable energy during the transition period. The findings should not be interpreted to mean that all renewable energy pathways are equivalent.

The positive coefficient on carbon emissions is interesting for other reasons. It is not proof that pollution is good for your health. In Sub-Saharan Africa, carbon emissions might also mean industrialization, building of roads, expanding electricity and economic activities. In industrialization and building of roads, hospitals and other services, emissions tend to rise. Improved means of transport, better hospitals and the addition of other public services that are critical, lead people to live longer. In every stage of development, the use of energy, the degradation of the environment, and economic growth are synonymous. In the literature, the effect of the high carbon system on health is often put at the forefront. Adeleye et al. (2022), Singh et al. (2025), and Osakede et al. (2025) say that higher emissions and dependency on fossil fuels are determinants of poor health and increased mortality, especially in low- and middle-income countries, and under the conditions of less renewable energy or direct exposure. The difference is more in the fact that in the African context, higher emissions are paired with better services and the dependence of life expectancy as a health indicator. The coefficient essentially captures a transitional effect of the development of pollution and therefore should not be taken in with so much optimism.

A contextual interpretation is also required for the positive correlation between urbanization and life expectancy. While urbanization leads to an increase in pollution, congestion, and environmental pressure, it also increases the accessibility of health care, education, electricity, transport, and sanitation. The agglomeration benefits of urbanization seem to outweigh the environmental costs in much of Sub-Saharan Africa, especially when there is adequate infrastructure and good governance. The results of the study indicate that the combination of renewable energy with urbanization strategies, peri-urban electricity access, and decentralized renewable energy for health facilities is

likely to have an effect in the areas of study. This is in addition to Beyene, and Kotosz (2021), which shows that in African countries, the quality of the environment is an important factor for an increase in the longevity of the population, and Warsame (2023) who shows that the combination of renewable energy, urbanization, and economic development has a positive effect on life expectancy. It also adds to the work of Segbefia et al. (2023) who in a different regional context found that renewable energy, innovation, and emissions closely interrelate with life expectancy.

The results directly address the third research question about the construction of policies. The largest takeaway is that renewableresources need to be integrated into development and public-health policies as a welfare-enhancing investment with health co-benefits. In other words, innovating and investing in renewable resources should not be regarded as an issue of only climate or energy development. Furthermore, In Sub-Saharan Africa, policy evaluation should and must include the benefits of the avoided health costs and the benefits of reducing exposures to pollution. pertaining to service(s) of rest, and increased resilience of the core or essential services infrastructure. The results also indicate that policy of renewable energy combined with other investments in health, urban development, and income will result in better policies. This translates into four policy priorities: decentralized renewable energy expansion for clinics and rural areas; speeding up transition to clean cookstoves; incorporating health co-benefits in energy planning and in the energy sector's cost-benefit analysis, and improving governance of the energy, health and environment sectors. These priorities have also been found in the works of Byaro and Rwezaula (2025), Osakede et al. (2025), and Singh et al. (2025).

This study shows that for the purpose of environmental economics and policy research, the values of renewable energy in Africa cannot be evaluated by carbon accounting. In energy impoverished and resource precarious and fragile health systems, the costs of polluting energy systems and unreliable energy systems extend costs beyond the obvious environmental costs. Health systems, service utility, and welfare effects are negatively impacted. The positive relationship observed between the consumption of renewable energy and life expectancy in Africa is further the the case for the positive relationship. This facilitates the case for the need to undertake policy evaluation in the energy sector in Africa and to take into account the health of co-benefits that will result from the investment in renewable energy.

Furthermore, the need to give further attention to the healthier side of the interpretation of the model case is warranted, as causal claims are stronger. The model is case based and examined intra-country relationships primarily, and as such, strong policy for positive relationships is maxed out. The positive renewable energy coefficient illustrates the need for further research in the area of positive health outcomes. Renewable subclass theory, especially between the modern and traditional biomass constitutive In Africa and the modern renewable resource constructs, should be confined to a specific type of unit in fragile health economics, low resource availability, low geographical spread of people,

and controlled movement of people. And so, for Sub-Saharan Africa Portal Africa, positive renewable energy transition, is a positive health outcome and a more simplified approach to achieving the sustainable development goals.

6. Conclusion

The study shows that health outcomes in Sub-Saharan Africa are influenced by a combination of environmental, economic, and structural factors, and not by any one factor in isolation. The positive and significant role of income, health expenditure, and urbanization supports the idea that renewable energy functions within a wider process of development. The positive sign on carbon emissions should be interpreted cautiously as development in the process and not the pollution of development itself. All in all, the findings confirm the energy–environment–health nexus and the need of an integrated approach in advocating for cleaner and reliable energy systems as means for improving the general health of the population. Evidence showing that renewable energy yields better life expectancy and health risks, while fossil fuel dependence and environmental destruction still lead to poor health outcomes in Africa and comparable situations is consistent with our findings (Adeleye et al., 2022; Beyene & Kotosz, 2021; Wang et al., 2023; Warsame, 2023; Singh et al., 2025).

When it comes to renewable energy investment in Sub-Saharan Africa, it should be seen through a dual-purpose approach to tackle both climate and health impacts, and so policies should go beyond just adding more electricity to the system. Policies should also focus on the integration of renewable energy with health system improvements, including electrification of clinics, and clean cooking solutions that reduce household air pollution. This is warranted as evidence grows that renewable energy, when combined with the right policies and investments, can reduce the number of people that die and increase overall health and wellbeing (Byaro & Rwezaula, 2025; Osakede et al., 2025; Uzoechina et al., 2024). African governments, therefore, should incorporate the positive health impacts of energy investments into their energy policies, the assessment of public investments, and their plans for development.

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Appendix

A. List of countries and years covered in the dataset

Country	Years covered
Angola	2000 to 2024
Benin	2000 to 2024
Botswana	2000 to 2024
Burkina Faso	2000 to 2024
Burundi	2000 to 2024
Côte d'Ivoire	2000 to 2024
Cabo Verde	2000 to 2024
Cameroon	2000 to 2024
Central African Republic	2000 to 2024
Chad	2000 to 2024
Comoros	2000 to 2024
Congo	2000 to 2024
Democratic Republic of the Congo	2000 to 2024
Equatorial Guinea	2000 to 2024
Ethiopia	2000 to 2024
Gabon	2000 to 2024
Gambia	2000 to 2024
Ghana	2000 to 2024
Guinea-Bissau	2000 to 2024
Kenya	2000 to 2024
Lesotho	2000 to 2024
Liberia	2000 to 2024
Libya	2000 to 2024
Madagascar	2000 to 2024
Malawi	2000 to 2024
Mali	2000 to 2024
Mauritania	2000 to 2024
Mauritius	2000 to 2024
Mozambique	2000 to 2024

Country	Years covered
Namibia	2000 to 2024
Niger	2000 to 2024
Nigeria	2000 to 2024
Rwanda	2000 to 2024
Senegal	2000 to 2024
Seychelles	2000 to 2024
South Africa	2000 to 2024
Sudan	2000 to 2024
Tanzania	2000 to 2024
Togo	2000 to 2024
Uganda	2000 to 2024
Zambia	2000 to 2024
Zimbabwe	2000 to 2024

B. Summary statistics

	Mean	Std. Dev.	Median	min	max	N
ln le	4.067	.111	4.085	3.747	4.306	594
ln rec	3.937	.741	4.165	.575	4.605	598
ln gdppc	6.885	1.033	6.721	4.697	9.81	675
ln he	1.471	.434	1.454	.102	3.09	611
ln co2	1.425	1.35	1.604	-1.905	4.882	675
ln urb	3.552	.476	3.626	2.085	4.52	675

C. Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) ln_le	1.000					

(2) ln_rec	-0.303	1.000				
(3) ln_gdppc	0.436	-0.443	1.000			
(4) ln_he	-0.020	0.306	-0.309	1.000		
(5) ln_co2	0.429	-0.195	0.454	-0.364	1.000	
(6) ln_urb	0.203	-0.303	0.623	-0.450	0.417	1.000

D. **Fisher ADF Tests**

(81 missing values generated)
Fisher-type unit-root test for le
Based on augmented Dickey-Fuller tests

Ho: All panels contain unit roots
Number of panels = 27

Ha: At least one panel is stationary
Number of periods = 22

AR parameter: Panel-specific
Asymptotics: T -> Infinity

Panel means: Included

Time trend: Not included

Drift term: Not included
ADF regressions: 1 lag

		Statistic	p-value
Inverse chi-squared(54)	P	123.9083	0.0000
Inverse normal	Z	-5.1383	0.0000
Inverse logit t(139)	L*	-5.4351	0.0000
Modified inv. chi-squared	Pm	6.7269	0.0000

P statistic requires number of panels to be finite.

Other statistics are suitable for finite or infinite number of panels.

E. Variance inflation factor

	VIF	1/VIF
ln rec	3.079	.325
ln urb	2.251	.444
ln gdppc	2.159	.463
ln co2	1.757	.569
ln he	1.329	.753
Mean VIF	2.115	.

F. Hasman test

Hausman (1978) specification test

	Coef.
Chi-square test value	17.845
P-value	.003

Regression with Driscoll-Kraay standard errors Number of obs = 577
Method: Fixed-effects regression Number of groups = 27
Group variable (i): country_id F(5, 21) = 473.72
maximum lag: 2 Prob > F = 0.0000
within R-squared = 0.7189

Drisc/Kraay

ln_le	Coef.	Std.Err.	t	P>t	[95%Conf.	Interval]
ln_rec	0.026	0.006	4.060	0.001	0.013	0.039
ln_gdppc	0.054	0.004	13.190	0.000	0.046	0.063
ln_he	0.030	0.004	6.810	0.000	0.021	0.039
ln_co2	0.035	0.005	6.780	0.000	0.024	0.046
ln_urb	0.132	0.013	10.090	0.000	0.105	0.160
_cons	3.058	0.033	91.840	0.000	2.988	3.127

G. GMM results

System GMM Regression results

ln_le	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
L	.76	.054	14.09	0	.654	.866	***
ln_rec	.014	.006	2.23	.026	.002	.026	**
ln_gdppc	.007	.004	1.51	.131	-.002	.016	
ln_he	.011	.007	1.55	.12	-.003	.025	
ln_co2	.004	.003	1.30	.193	-.002	.009	
ln_urb	-.022	.011	-1.99	.046	-.043	0	**
Constant	.947	.198	4.78	0	.559	1.335	***

Mean dependent var	4.076	SD dependent var	0.104
Number of obs	552	Chi-square	4572181.465

*** p<.01, ** p<.05, * p<.1