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RESEARCH ARTICLE

Energy consumption habits and human health nexus in Sub-Saharan Africa

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Abstract
This study explores the impact of fossil fuels consumption, solid fuels consumption for cooking purposes, economic growth, and carbon emissions on human health, with a key emphasis on the occurrence of tuberculosis and the high mortality rate in Sub-Saharan Africa. For its practical insights, the study develops a system Generalized Method of Moment (GMM) for a panel of 34 middle- and lower-middle-income countries from 1995 to 2015. The study adopts a flexible methodology to tackle endogeneity in the variables. The robust results report that the use of solid fuels (charcoal, peat, wood, wood pellets, crop residues) for cooking purposes and the consumption of fossil fuels (oil, coal, gas) are significantly increasing the occurrence of tuberculosis. In addition, the results highlight that the consumption of both solid fuels and fossil fuels has adverse affects on life expectancy by increasing the mortality rate in Sub-Saharan African countries. Results report that renewable energy sources like sun, wind, and water (all with potential to prevent households from direct exposure to particulate matters and harmful gases) as well as a rise in economic growth serve as helping factors to control the occurrence of tuberculosis and to decrease the mortality rate. Moreover, the use of renewable energy sources is serving to lessen emissions of carbon dioxide, nitrogen dioxides, and particulate matters, which can ultimately decrease the mortality rate and extend the life expectancy in Sub-Saharan Africa.

Keywords Energy consumption habits · Economic growth · Human health · Mortality rate · Tuberculosis · Sub-Saharan Africa

Introduction

The developing economies of Sub-Saharan Africa are facing the dual challenges of poor economic development and continuously increased use of fossil fuels such as oil, coal, and gas to improve the living standards of households. Although consumption of such non-renewables has served to accelerate the economic wheel, it meanwhile generates residues in the form of toxic gases and exerts adverse impacts on the health of biological life in the region (Chaabouni and Saidi 2017). In order to combat any number of economic challenges, and to promote the living standards of their populations, these developing countries cannot compromise on the promotion of economic development. Therefore, residents of developing countries have been consuming readily available energy sources in the form of fossil fuels (oil, coal, gas) and solid fuels (charcoal, peat, wood, wood pellets, crop residues) to meet their outdoor and indoor energy requirements, overlooking the adverse impact of toxic gases on human health (Lobell et al. 2008; Hanif and Gago-de-Santos 2017; Hanif 2017). Worldwide, approximately 2.8 billion individuals—almost 41% households—use solid fuels for heating and cooking purposes (Bonjour et al. 2013). Nigeria, Ghana, Cameroon, Madagascar, Mauritius, Uganda, and South Africa in particular are ranked highest among the developing countries of Sub-Saharan Africa in terms of damages of observed peak greenhouse gas emissions. Globally, in 2016, 4.3 million premature deaths from ambient outdoor pollution and 2.6 million from indoor pollution were reported as a result of air pollution (Roser and Ritchie 2018). It is alarming that, due to air pollution, almost half a million people die each year in Sub-Saharan Africa (World Health Organization 2016). Moreover, environmental degradation

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is not only endangering health; it is also threatening regional opportunities for livelihood. For instance, the production of cocoa beans is a primary source of livelihood in the majority of African countries, and the rise of cadmium levels in cocoa beans is diminishing the long-term prospects for that livelihood. The primary objective of this study is therefore to highlight and quantify the influence of carbon emissions, fossil fuels, and solid fuels consumption on human health. While fossil and solid fuels are doubtless helping to meet energy requirements, they are also manifesting new challenges, not least in the form of health problems including lung cancer, latent tuberculosis, and other pulmonary diseases (Smith et al. 2014; Chaabouni and Saidi 2017).

Almost half of the global population is located in low-income countries and uses fossil fuels and solid fuels for heating and cooking purposes. More precisely, about 3.4 billion individuals burn solid fuels, and as a result 1.5 million premature deaths are recorded each year (Sumpter and Chandramohan 2013). Numerous studies have been conducted to examine the role of fossil and solid fuels on the prevalance of tuberculosis and premature deaths in developing countries, and many link the pollutants generated by use of fossil and solid fuels with an elevated risk of tuberculosis (see Appendix Table 8 for further details). Moreover, combustion of fossil and soild fuels generates atmospheric particulate matter (PM2.5), nitrous oxides, formaldehyde, nitrogen dioxides, and carbon monooxide, all of which affect the self-clearing mechanisms of the bronchia. Exposure to particulate matter and gas emissions from fossil and solid fuels consumption increases inflammation and reduces the antibacterial effect of lungs, which in turn has implications in leading to a higher risk of tuberculosis and poor lung health (Lin et al. 2007). Lin et al. (2008) conducted a meta-analysis study in China and found that consumption of solid fuels is likely to be related to latent tuberculosis infection, as well as to the progression of active tuberculosis. They further stressed that consumption of fossil and solid fuels is a primary cause of both outdoor and indoor pollution in urban areas. Jubulis et al. (2014) depict a strong association between tuberculosis and indoor exposure to air pollution. Moreover, fossil and solid fuels are the primary sources of particulate matter (PM2.5) emissions, demanding determination of the impact of such fuel consumption on the occurrence of tuberculosis through a range of outdoor and indoor energy and heating sources. Economic growth is also necessary for developing countries to combat various socio-economic challenges including poverty, food insecurity, and a lack of basic health facilities. The enormous consumption of solid and fossil fuels needed to meet energy requirements is intensifying, and this is manifesting both health and economic issues. That is to say, various environmental and health challenges are linked with the prevailing development style in the region under question. Therefore, to cope with health issues, it will be necessary to develop and follow a sustainable pattern of economic progress.

This study focuses on Sub-Saharan African economies because that region faces numerous health issues and a distorted position in terms of climate change (Hanif 2018b). At the regional level, an average growth rate of 2.6% in carbon emissions was recorded for the period 2005–2015 (World Health Organization 2016). Moreover, like other regions of the world, fossil and solid fuels in Sub-Saharan Africa are the primary sources for meeting household energy requirements. About 730 million individuals in African countries rely on dangerous and inefficient forms of cooking, using solid fuels like charcoal, peat, wood, and wood pellets abundantly. It is therefore essential to quantify the impact of indoor energy consumption (as with these cooking habits) on the mortality rate and incidence of tuberculosis in households (Sumpter and Chandramohan 2013; World Health Organization 2016).

The second objective of this study is to examine the impact of outdoor fossil fuels consumption on mortality rates and tuberculosis in the developing economies of Sub-Saharan African, and the third objective is to examine the impact of CO_2 emissions on human health. The study meanwhile seeks to highlight the advantages of cleaner energy, as can be produced from wind, water, and sunlight. Accentuating the importance and influence of such renewable energy sources on human health is another key objective of the study. In short, this article complements the existing literature by exploring the impact of non-renewable outdoor and indoor energy consumption habits, CO_2 emissions, and renewable energy consumption on human health in the upper-middle-, lower-middle-, and low-income countries of Sub-Saharan Africa. In order to report the latest insights, data from 34 developing countries is analyzed, covering the period of 1995 to 2015.

Many earlier studies have confirmed the harmful effects of carbon emissions on human health (i.e., Janke et al. (2009) and Beatty and Shimshack (2014)). The present study contributes by examining the impact of both solid and fossil fuels consumption, as well as of renewable energy resources, on the occurrence of tuberculosis and the overall mortality rate.

As mentioned, various energy and environment indicators are used in the literature to determine the impact on health status. But indicators on energy consumption, carbon emissions, and economic growth can be said to "cause" one another, which may lead to simultaneity bias in the estimation procedure and yield spurious results (Hanif 2018a; Chaabouni and Saidi 2017). Indeed, it is impossible to incorporate all energy and environment indicators into a single model, and overlooking a necessary energy or health indicator in the construction of an econometric model can yield omitted variable or model misspecification bias (Chaabouni and Saidi 2017). To mitigate simultaneity and omitted variable biases, and to report the influence of energy and carbon emissions on health status, this study employs a highly flexible one-step system Generalized Method of Moment (GMM).

The emphasis of the present research is to answer the following questions: (1) Do indoor and outdoor energy consumption habits increase the mortality rate and occurrence of tuberculosis in Sub-Saharan African countries? (2) Do carbon emissions increase the occurrence of tuberculosis and mortality rate in that same region? (3) Is renewable energy helpful for controlling tuberculosis and reducing the mortality rate in middle- and lower-income countries? (4) How do GDP growth and urban sprawl effect human health? Our analyses generate robust results that lead us to propose effective policy suggestions for helping overcome health challenges such as the high incidence of tuberculosis and high mortality rate in the developing countries of Sub-Saharan Africa.

The rest of the paper is organized as follows: a summary of crucial health and energy indicators is presented in Section 2. In Section 3, the data and methodological framework are constructed. Empirical results are reported and discussed in Section 4, and Section 5 collects our conclusions.

Summary of key health and energy indicators

Health status, energy consumption, economic growth, urbanization, and carbon emissions in Sub-Saharan Africa

Compared with developed economies, the dire consequences of natural resource depletion and exploitation for populations in the developing economies are much higher. The developing economies of Sub-Saharan Africa face numerous socio-economic challenges, health problems, and environment and land degradation issues (Machol and Rizk 2013). Likewise, the Agbloboshine region of Ghana's capital city Accra is ranked among the ten most polluted places of the world, and those who reside there are continuously exposed to toxic fumes produced by the dumping of electronic waste, and thus facing serious health issues. Moreover, the dumping of electronic waste is threatening local communities traditionally engaged in the cultivation of cocoa beans, due to rising cadmium levels in that crop. Similarly, in Nigeria, the state of Lagos is considered a commercial hub and generates 12,000 metric tons of waste on daily basis, which exceeds the limits of local waste management facilities (Williams et al. 2015; World Health Organization 2016; Machol and Rizk 2013). Onitsha City in southern Nigeria is ranked especially high in the generation of particulate matters that generate respiratory diseases such as asthma and tuberculosis. According to a World Health Organization report, around 94% of the Nigerian population (and an average 72% of Sub-Saharan Africa overall) is exposed to severe air pollution, and therefore facing increased health problems (World Health Organization 2016). In economic terms, the annual damages fomented by air pollution in Sub-Saharan Africa is estimated at about 1% of the combined Gross National Incomes. Places like Bamenda and Bafoussam in Cameroon, Antananarivo in Madagascar, Beau Bassin and Rose Hill in Mauritius, Kampala in Uganda, and Hartebeespoort and Pretoria in South Africa are all continuously spewing toxic gases into the air. These cities are having to confront the consequences of environmental and land depletion as well as higher health expenditures to combat related issues in the region (Faivre et al. 2017). While economic growth is undoubtedly necessary to cope with many socio-economic challenges, and to perpetuate these developing nations by fostering further growth, there is an excessive reliance on fossil and solid fuels to manufacture goods, and a healthy environment is often considered to be a luxury that cannot be afforded (Faivre et al. 2017; Helbich 2018). The average current values of mortality rates, reported cases of tuberculosis, fossil fuels consumption, carbon dioxide emissions, real per capita gross domestic product, household consumption of solid fuels for cooking, and urbanization in the Sub-Saharan African countries are presented below in Table 1.

Data and methodology

To examine the effect of fossil fuels consumption, the growth of real per capita gross domestic product, carbon emissions, consumption of solid fuels for cooking, and urbanization on health status in Sub-Saharan Africa, a panel data is utilized from 34 countries for the period 1995 to 2015. In the present study, the empirical analysis is limited to 34 developing countries due to data deficiencies in a few crucial variables. In addition data of few countries available until 2012, therefore the present study uses an unbalance panel data for econometric analysis. The data was extracted from World Development Indicators (WDI), the BP Statistical Review of World Energy, and the World Health Organization (WHO). Comparisons of non-renewable and renewable energy consumption against health indicator data have been made from 1995 to 2015, pre-1995 data being unavailable. Moreover, as developing countries face especially severe problems, we bear that distinction in mind and break our

Table 1 Averages of key indicators in Sub-Saharan African nations (1995–2015)

Country name	CO_2 (kt) emissions	Fossil fuels energy (kWh)	GDP growth per capita	% of Households using solid fuels	Urban agglomeration	Mortality rate (per 1000 individuals)	Reported cases of tuberculosis (per 100,000 individuals)
Angola (LMI)	18,442.89	499.79	4.21	73.56	23.34	14.23	360.18
Benin (LI)	3077.96	309.75	1.35	95.37	7.82	11.35	71.18
Botswana (UMI)	3916.54	908.56	2.79	56.44	10.41	11.35	628.25
Burkina Faso (LI)	1421.25	81.54	2.95	96.51	10.21	13.05	61.06
Cabo Verde (LMI)	301.08	39.32	5.17	51.34	7.83	5.90	149.75
Cameroon (LMI)	4612.89	333.74	1.45	84.06	20.43	13.26	279.06
Chad (LI)	332.15	52.76	3.41	96.31	8.56	16.43	151.75
Congo, Dem. Rep. (LI)	1701.48	269.97	0.07	96.94	20.67	13.65	326.62
Congo, Rep. (LMI)	1412.37	304.81	1.25	84.31	35.81	11.58	394.93
Cote d'Ivoire (LMI)	7145.63	424.34	0.82	85.93	19.49	15.35	242.06
Ethiopia (LI)	5311.16	407.53	5.01	97.24	3.46	11.27	305.87
Gambia, The (LI)	338.32	15.03	0.37	96.54	7.82	10.34	183.12
Ghana (LMI)	8164.47	298.14	3.24	89.81	15.89	9.82	191.25
Guinea (LI)	1641.46	65.87	0.42	98.35	14.50	13.15	199.12
Kenya (LMI)	9973.66	415.25	1.42	86.67	9.80	9.70	308.25
Lesotho (LMI)	1945.54	12.44	2.68	71.08	13.73	14.70	1102.81
Malawi (LI)	959.40	9.32	2.19	97.98	8.23	13.15	343.06
Mali (LI)	842.83	6.43	1.78	98.41	11.60	15.29	66.50
Mauritius (LMI)	3088.77	825.41	3.85	27.39	9.45	7.10	22.50
Mozambique (LI)	1995.81	361.66	5.44	97.55	5.08	14.32	533.5
Namibia (UMI)	2297.27	580.51	2.51	68.47	6.49	10.23	728.68
Niger (LI)	968.28	87.17	0.59	97.89	5.93	14.64	132.43
Nigeria (LMI)	79,106.84	660.77	3.53	80.88	14.10	16.01	336.31
Rwanda (LI)	557.96	008.43	6.23	98.51	8.78	12.83	88.87
Senegal (LI)	5182.43	228.67	1.33	70.86	21.52	8.94	141.31
Sierra Leone (LI)	635.74	11.43	1.58	97.58	15.93	19.75	313.50
South Africa (UMI)	423,376.6	2414.5	1.22	38.43	33.25	12.03	862.87
Sudan (MI)	10,200.05	345.53	3.87	84.98	12.51	9.28	111.25
Swaziland (MI)	1031.77	69.89	1.80	72.33	21.82	13.01	1094.12
Tanzania (LI)	5132.44	379.11	2.95	96.68	7.61	10.99	446.50
Togo (LI)	1587.61	390.79	0.95	97.26	4.68	11.31	66.00
Uganda (LI)	2360.77	5.38	3.41	97.97	4.71	13.08	226.68
Zambia (LMI)	2333.94	546.06	2.87	88.26	11.34	13.64	557.25
Zimbabwe (LI)	12,003.44	685.41	0.47	76.47	10.73	13.63	478.43

Source: Author's calculation based on World Bank Data (1995–2015)

LI low-income, *LMI* lower-middle income, *UMI* upper-middle income countries

sample into (upper- and lower-) middle income and low-income country groups, according to the World Bank's per capita income classifications.

Model specification

The functional form of the model used in the study is given as:

$$Hlt = f(OE, IE, \omega)$$

The functional form can be converted into a simple linear econometric model as follows:

$$Hlt_{it} = \gamma_0 + \gamma_1 OE_{it} + \gamma_2 IE_{it} + \omega_k \pi_{it} + \mu_{it} \quad (1)$$

Here, π_{it} is a set of additional control variables, ω_k is the slope of additional control variables, and μ_{it} is an idiosyncratic error term in "i" country and in "t" time period. After including additional independent variables to examine the effect of outdoor and indoor energy consumption habits, renewable energy consumption, economic growth, urbanization and carbon emissions on mortality rate, and on the occurrence of tuberculosis in Sub-Saharan Africa, the extended form of Eq. (1) can be written as follows.

Model 1

$$MOR_{it} = \gamma_0 + \gamma_1 OEC_{it} + \gamma_2 IEC_{it} + \gamma_3 REC_{it} + \gamma_4 GDP_{it} + \gamma_5 URB_{it} + \gamma_6 ENV_{it} + \mu_{it} \quad (2)$$

Model 2

$$TUB_{it} = \gamma_0 + \gamma_1 OEC_{it} + \gamma_2 IEC_{it} + \gamma_3 REC_{it} + \gamma_4 GDP_{it} + \gamma_5 URB_{it} + \gamma_6 ENV_{it} + \mu_{it} \quad (3)$$

Descriptions of variables

Mortality rate (MOR) Mortality rate per 1000 individuals is used as a dependent variable to demonstrate the health standard of households in Eq. (2).

Occurrence of tuberculosis (TUB) The occurrence of tuberculosis is measured as the number of cases reported per 100,000 individuals, used as a dependent variable in Eq. (3).

Outdoor energy consumption habits (OEC) Annual per capita fossil fuels consumption in kilograms of oil equivalent is used to examine the impact of fossil fuels consumption on dependent variables. The study hypothesizes that the use of fossil fuels to produce energy generates nitrogen dioxides and carbon monoxide, causing the mortality rate and chances of occurrence of tuberculosis to increase.

Indoor energy consumption habits (IEC) The share of total population using solid fuels for cooking is considered in order to examine the impact of solid fuels use on household health status. According to this hypothesis, increases in solid fuels consumption raise the mortality rate and the incidence of tuberculosis.

Renewable energy consumption (REC) Annual per capita renewable energy consumption in kilograms of oil equivalent is used as our basis to examine the impact of renewable energy consumption on health. The study hypothesizes that use of renewable energy sources reduces the mortality rate and the incidence of tuberculosis.

Real per capita gross domestic product (GDP) Here, annual real per capita gross domestic product in 2010 US$ is used to examine the impact of economic growth on the health status of individuals. According to the hypothesis, an increase in per capita gross domestic product reduces the mortality rate and the incidence of tuberculosis.

Population in urban agglomeration (URB) Population in urban agglomerations of more than one million individuals is used to measure the pace of urbanization in the region. To measure urban agglomeration, populations over one million living in continuous urban areas including suburbs are considered. According to the hypothesis, growth of urban agglomeration increases the mortality rate and the incidence of tuberculosis.

Environmental degradation (ENV) The annual rate of per capita carbon emissions in metric tons is used as an independent variable. The study hypothesizes that carbon emissions are a major cause of raised temperatures, which convert nitrogen and oxygen into nitrogen oxides (NO_x); as a result, this increases the incidence of tuberculosis and the death rate (Table 2).

Results estimation and discussion

Empirical estimation

The summary statistics of dependent and independent variables used in Eqs. (1) and (2) are given in Table 3.

The results of a pair-wise correlation matrix to examine the multicollinearity in the selected variables are given in Table 4.

The results show that the mortality rate (*MOR*) and incidence of tuberculosis (*TUB*) are weakly correlated with outdoor energy consumption (*OEC*), indoor energy consumption (*IEC*), renewable energy consumption (*REC*), per capita gross domestic product (*GDP*), urban agglomeration (*URB*), and carbon emissions (*ENV*). Thus, results of the pair-wise correlation matrix show that the estimated models have no multicollinearity.

It is also essential to examine the stationarity of the dependent and independent variable series used in both of the models. As our variables consist of data series from different countries, and due to some missing values, we are working with unbalanced panel data. Therefore, a Fisher-type unit root test is applied here to examine the stationarity in the data series and results are given in Table 5.

The result of unit root test firmly rejects the null hypothesis; i.e., data series contain a unit root. Thus, the result of unit root test shows that the dependent and independent variables are stationary at level. Moreover, in order to report robust results, heteroscedasticity and endogeneity in both models are tested by way of Breush-Pagan and Durbin-Wu-Hausman tests, respectively, and the results are given in Table 6.

Table 2 Description of variables

Variables	Description	Unit of measurement	Source
MOR	Mortality rate	Per 1000 individuals	World Development Indicators, World Bank 2016
TUB	Occurrence of tuberculosis	Per 100,000 individuals	Health Indicators, World Health Organization 2016
OEC	Per capita fossil fuels consumption	Kilograms of oil equivalent	World Development Indicators, World Bank 2016
IEC	Per capita solid fuels consumption for cooking	Kilograms of oil equivalent	World Development Indicators, World Bank 2016
REC	Per capita renewable energy consumption	Kilograms of oil equivalent	BP Statistical Review of World Energy
GDP	Real per capita gross domestic product	Constant 2010 US$	World Development Indicators, World Bank 2016
URB	Population in urban agglomeration	More than 1000,000 individuals	World Development Indicators, World Bank 2016
ENV	Per capita CO_2 emissions	Metric tons	World Development Indicators, World Bank 2016

Source: compiled by author

Here, the lower *p* values of the Breush-Pagan and Durbin-Wu-Hausman tests confirm the rejection of a null hypothesis of constant variance in the parameters and the exogenous variables. To tackle issues of heteroscedasticity and endogeneity in the models, our analysis uses a system GMM to estimate the impact of outdoor and indoor energy consumption habits on the mortality rate and incidence of tuberculosis in developing Sub-Saharan African countries. In addition, to deal with endogeneity in the variables, Arellano and Bond (1988) recommend a difference GMM. The differerence GMM uses first-difference lag variables as an instrument for the identical moment conditions. However, the use of first-difference lag variable as an instrument often leads to a severe deviation bias, particularly in the case of limited samples, and it mostly proves the weakness of instruments. Therefore, Arellano and Bover (1995) and Blundell and Bond (1998) recommend a system GMM in which instruments are developed by using differences as well as level information. The introduction of a level equation into a system GMM converts the lagged variables of the level equation into instruments, and as a result the number of instruments increases. Thus, system GMM provides more information on the sample compared to difference GMM. Moreover, in the case of a limited sample, the use of two-step GMM generates a downward bias, and Windmeijer's (2005) adjustment is generally used to reduce that bias, although this leads to an unreliable approximate asymptotic distribution. Consequently, our analysis employs a one-step system GMM and uses the robust version to mitigate endogeneity and heteroscedasticity, respectively. However, the validity of the parametric estimation depends on the quality of instruments used to control endogeneity. Therefore, the Hansen test is applied to examine the validity and quality of instruments used to control endogeneity in the models, and the results are given in Table 7.

Results and discussion

The results, presented in Table 7, highlight that outdoor energy sources (i.e., combustion of fossil fuels and consumption of solid fuels for cooking, to meet indoor energy requirements) are significantly contributing to the incidence of tuberculosis and increasing the mortality rate in middle- and low-income countries of Sub-Saharan Africa. More precisely, if all other factors are considered constant, consumption of each additional kiloton of fossil fuels increases the mortality rate per thousand individuals by about 0.41 units, and it raises the

Table 3 Summary statistics

Variables	Obs.	Mean	Median	Maximum	Minimum	Std. dev.
MOR	714	11.74	11.58	23.98	5.45	3.26
TUB	714	338.0	277.0	1354.0	21.0	284.43
OEC	680	458.12	455.79	796.63	129.06	1.70
IEC	639	82.36	81.81	97.81	55.71	12.44
REC	639	72.81	77.48	94.08	21.21	19.83
GDP	714	1321.94	1095.18	3972.61	311.24	9.94
URB	684	5,303,432	4,110,016	25,366,174	942,572	5.91
ENV	711	0.38	0.29	1.48	0.04	0.35

Source: authors' calculation

Table 4 Correlation matrix

	MOR	TUB	OEC	IEC	REC	GDP	URB	ENV
MOR	1.00							
TUB	0.38	1.00						
OEC	− 0.20	0.54	1.00					
IEC	0.26	0.23	0.05	1.00				
REC	0.32	− 0.31	− 0.09	0.13	1.00			
GDP	0.07	0.26	0.12	0.21	0.17	1.00		
URB	− 0.22	0.23	0.24	− 0.18	0.34	0.32	1.00	
ENV	0.25	0.03	0.08	0.21	0.17	0.01	0.13	1.00

Source: authors' calculation

incidence of tuberculosis by about 0.81 units per 0.1 million individuals (again, in the developing countries of Sub-Saharan Africa). The results further examine the influence of fossil fuels consumption on health outcomes and spotlight that consumption of fossil fuels is significantly aggravating health issues in the region. Mostly in developing economies, fossil fuels are massively used to meet energy demand and to foster economic growth (Sapkota et al. 2013; Hanif 2017). Like other developing nations, the countries of Sub-Saharan African also face myriad socio-economic challenges and are struggling to improve living standards by increasing the production of goods and services (Etchie et al. 2017). In order to meet rising energy demand, these countries are using vast amounts of fossil fuels and generating waste in the form of toxic gases, which in turn are contributing adversely to health status and especially to pulmonary diseases such as tuberculosis and asthma, above and beyond the environmental issues these practices create throughout the region. The findings of our study endorse the results of Lin et al. (2008), Po et al. (2011), Sapkota et al. (2013), Sumpter and Chandramohan (2013), and Kim (2014), confirming that fossil fuels consumption is adversely affecting health in middle- and low-income countries of the sample.

The results further depict that consumption of solid fuels (such as charcoal, coal, peat, wood, wood pellets, and residues of wheat and rice used for cooking purposes) has a significant and positive influence on the incidence of tuberculosis and the mortality rate. Specifically, the results show that an increase of one kiloton in the consumption of solid fuels for cooking increases the mortality rate and occurrence of tuberculosis by about 0.69 and 1.88 units, respectively. Thus our results demonstrate that the combustion of solid fuels for cooking purposes represents a critical sources of direct exposure to particulate matters ($PM_{2.5}$) and toxic gases such as carbon monooxide (CO) and nitrogen oxides (NO_x), consequently generating severe health issues at the regional level. These results endorse the finding of Champion et al. (2017), Machol and Rizk (2013), Sumpter and Chandramohan (2013), Epstein et al. (2013), Debbi et al. (2014), and Quansah et al. (2015). Our findings suggest that increased access to clean cooking facilities (switching to alternative fuels) is necessary for improved health outcomes. Access to improved biomass cookstoves can efficiently reduce the direct exposure of households to toxic gases by minimizing indoor pollution (Williams et al. 2015; Machol and Rizk 2013; Epstein et al. 2013). Additionally, awareness-raising programs and the introduction of renewable energy modes can be effective ways to protect households from toxic gases and to improve the health of individuals (Clark et al. 2013; Sinton et al. 2004).

The results demonstrate that consumption of renewable energy sourcces has a negative impact on mortality and the incidence of tuberculosis, and this highlights that a transition from fossil and solid fuels to renewables would improve the

Table 5 Results based on Fisher-type unit root tests

AR parameter: panel-specific		Number of panels = 34							
Group means: included		Avg. number of periods = 17.85							
Time trend: not included		Cross-sectional means removed							
Drift term: included		ADF regressions: (0) lags							
		MOR	*TUB*	*OEC*	*IEC*	*REC*	*GDP*	*URB*	*ENV*
Inverse chi-squared	P	58.34	61.03	82.47	87.53	93.52	62.17	66.13	58.63
Inverse normal	Z	− 5.22	− 5.07	− 5.14	− 6.42	− 8.32	− 6.32	− 7.83	− 5.79
Inverse logit-t	L*	− 6.09	− 9.92	− 5.79	− 9.48	− 13.22	− 8.54	− 11.28	− 7.34
Modified inv. chi-squared 9.84		Pm	8.23	7.96	8.26	12.08	19.32	8.42	16.39

Source: authors' calculation. Note: Here the null hypothesis (H_0: all panels contain unit roots) is rejected by the results of Fisher-type unit root test, commonly used for unbalanced panel data. Thus we conclude that all data series are stationary at level

Table 6 Results of diagnostic tests

Model 1: results of Breush-Pagan heteroscedasticity test	
Dependent variable: *MOR*	Independent variables: *OEC*, *IEC*, *REC*, *GDP*, *URB*, *ENV*
Chi2(6)	67.199
Prob> chi2	0.001
Model 2: results of Breush-Pagan heteroscedasticity test	
Dependent variable: *TUB*	Independent variables: *OEC*, *IEC*, *REC*, *GDP*, *URB*, *ENV*
Chi2(6)	89.73
Prob> chi2	0.000
Model 1: results of Durbin-Wu-Hausman endogeneity test	
Dependent variable: *MOR*	Independent variables: *OEC*, *IEC*, *REC*, *GDP*, *URB*, *ENV*
Durbin (score) chi2(6) = 56.532	($p = 0.01$)
Wu-Hausman F(6,639) = 97.71	($p = 0.00$)
Model 2: results of Durbin-Wu-Hausman endogeneity test	
Dependent variable: *TUB*	Independent variables: *OEC*, *IEC*, *REC*, *GDP*, *URB*, *ENV*
Durbin (score) chi2(6) = 81.623	($p = 0.00$)
Wu-Hausman F(6,639) = 103.002	($p = 0.00$)

Source: authors' calculation. Note: The results of Bresush-Pagan test reject the null hypothesis of constant variance in models 1 and 2. The lower *P*-value in the endogeneity test indicates rejection of null hypothesis for both models, which also confirms endogeneity in the independent variables

Table 7 Results of one-step GMM (robust) estimation

	Model 1			Model 2		
	Dependent variable = MOR			Dependent variable = TUB		
	Developing countries	Lower-middle income	Low-income	Developing countries	Lower-middle income	Low-income
Outdoor energy consumption	0.414*** (0.162)	0.215** (0.107)	0.781*** (0.232)	0.814*** (0.338)	0.702*** (0.295)	0.916*** (0.342)
Indoor energy consumption	0.692*** (0.203)	1.052*** (0.269)	1.941*** (0.736)	1.881*** (0.804)	2.026** (1.006)	2.744*** (0.916)
Renewable energy consumption	−0.048* (0.027)	−0.067** (0.031)	−0.093* (0.052)	−0.027* (0.016)	−0.069** (0.032)	−0.188** (0.091)
Per capita real GDP	−1.078** (0.579)	−0.875** (0.461)	−1.071** (0.481)	−1.993** (0.989)	−1.205** (0.638)	−0.972** (0.484)
Urbanization growth	0.131*** (0.056)	0.094*** (0.012)	0.015** (0.008)	0.098** (0.018)	0.288** (0.089)	0.008*** (0.003)
Environmental degradation	0.195*** (0.094)	1.025*** (0.063)	1.897*** (0.282)	1.636** (0.942)	1.004** (0.458)	2.188** (1.177)
Constant	2.094*** (0.913)	1.834*** (0.589)	1.075*** (0.097)	3.652*** (1.036)	4.673*** (1.493)	6.822*** (1.699)
Number of panels	34	16	18	34	16	18
Observations	607	285	322	607	285	322
Instruments	29	13	16	31	15	17
Wald chi2(6) Prob.	2368.93 (0.000)	1437.13 (0.000)	2265.78 (0.000)	582.98 (0.000)	321.22 (0.000)	109.01 (0.000)
Hansen J-test Prob.	20.005 (0.1263)	16.779 (0.114)	23.672 (0.161)	13.05 (0.168)	11.54 (0.142)	11.99 (0.128)

Source: authors' calculation. Note: Here ***, **, and * represent the 1, 5, and 10% level of significance, respectively. The heteroscedastic consistent standard error is in parentheses. Hansen J-test of overidentifying restrictions shows acceptance of the null hypothesis that overidentifying restrictions are valid health status of individuals mainly by controlling the emission of toxic gases and particulate matters in these developing economies. Furthermore, an improvement in per capita real gross domestic product has a negative and significant impact on mortality rates and incidences of tuberculosis. More precisely, the results indicate that each unit increase in per capita gross domestic product reduces the mortality rate and the incidence of tuberculosis by about 1.07 and 1.99 units, respectively. The results further show that the promotion of economic growth coupled with renewable energy consumption in these developing countries would prove significant to reducing the mortality rate and controlling the incidence of tuberculosis, thus endorsing the prior findings of Deichmann et al. (2011). A transition from solid and fossil fuels to alternative renewable energy sources is indispensable to controlling both the indoor and outdoor exposure of individuals to toxic gases and particulate matters, extending life expectancy by reducing tuberculosis and the death rate (Rehfuess et al. 2014).

Results also show that urbanization has a significant and positive impact on mortality and the incidence of tuberculosis in Sub-Saharan Africa. According to our findings, each unit increase in urbanization increases the mortality rate and the incidence of tuberculosis by about 0.13 and 0.09 units, respectively, thus endorsing the results of Fan et al. (2016) and Helbich (2018). However, in Sub-Saharan Africa, urban expansion is seen as necessary for populations' well-being; and while rapid urban development in the region although does have positive economic and social effects on the lives of individuals, at the same time it increases energy demand, especially for the provision of transportation, public utilities, and other services (Harpham and Stephens 1991; Chen et al. 2004; World Health Organization 2016). These results endorse the findings of Gninafon et al. (2011), Nadal et al. (2015), and Lakshmi et al. (2012), and they suggest that urban sprawl in the region is putting pressure on natural resources and producing negative externalities in the form of health problems.

The study also uses carbon emissions to quantify the impact of environmental degradation on health outcomes. The results show a significant and positive influence of environmental degradation on mortality and the incidence of tuberculosis in Sub-Saharan African countries. More precisely, each additional kiloton of carbon dioxide emissions increases the mortality rate and incidence of tuberculosis by about 0.19 and 1.63 units, respectively. These findings are in line with those of Williams et al. (2015), Barnes (2014), Vineis et al. (2014), Singh and Sachs (2013), Sumpter and Chandramohan (2013), Epstein et al. (2013), and Deichmann et al. (2011). Overall, the empirical results underline that, in developing economies, environmental health is treated as a luxury. At the same time, there is a need to understand the cost and damages of negative externalities ocurring as a by-product of the massive consumption of fossil and solid fuels. Our empirical results would discourage the use of fossil and solid fuels to meet outdoor and indoor energy requirements, pointing to the importance of renewable energy and economic growth to increase life expectancy by controlling the incidence of tuberculosis and the high mortality rate currently seen in middle- and low-income countries of Sub-Saharan Africa.

Conclusions

The study shows that fossil and solid fuels consumption for cooking purposes and urbanization and carbon emissions are the principal sources of high mortality rate and occurrence of tuberculosis in Sub-Saharan Africa. However, the promotion of economic growth is essential to reducing the mortality rate and to overcoming the incidence of tuberculosis. This study concludes that renewable energy is a valuable source for improving the health status and for reducing both the outdoor and indoor exposure of individuals to particulate matters and toxic gases. Our findings suggest there is a need for national and international agreements to move economies from fossil and solid fuels consumption to renewable energy sources, to help address these serious health issues at the regional level. The use of solid fuels for cooking not only affects the environment but creates health problems, notably increasing the incidence of tuberculosis in the region. Thus there is further need to switch to alternative cooking fuels, such as biomass cookstoves, which can efficiently reduce direct contact of individuals to particulate matters and poisonous gases and help to control tuberculosis by diminishing indoor pollution. The empirical results also show that a rise in emissions of toxic gases and particulate matter due to massive consumption of fossil and solid fuels is challenging the achievement of sustainable development in these middle- and low-income countries. Investment in clean energy infrastructures is required, particularly in Sub-Saharan Africa, where less is known about the adverse impact of fossil and solid fuels consumption on human health. In short, there is a need to take proactive measures to tackle the health and environmental challenges at the regional and national levels: cleaner energy sources, carbon taxing, tuberculosis awareness programs, and so on. In these developing economies, the use of solid fuels for cooking and the high consumption of fossil fuels are exacerbated by the absence of basic education on these topics. The promotion of knowledge and innovation among economic actors, health professionals, environmental scientists, and policy makers on issues of renewable energy and awareness around the adverse impacts of fossil and solid fuels on health and the environment could efficiently improve well-being and control particulate matter and toxic gases emissions at the regional level. In order to lessen the impact of fossil and solid fuels consumption on human health, there is a need to develop sound economic, social, and environmental policies at both the community and national levels.

Appendix

Table 8 Summary of key significant studies

Author(s)	Area of study	Sample size and age	Method	Dependent variable	Independent variable	Results
Pokhrel et al. (2010)	Urban/rural India	> 20-year-old females (Obs. 378)	Multivariate logistic regression	Tuberculosis	Biomass/solid fuels use	Positive association
Kolappan and Subramani (2009)	Urban/rural Nepal	> 20-year-old females (Obs. 375)	Multivariate logistic regression	Tuberculosis	Biomass/solid fuels use	Positive association
Lakshmi et al. (2012)	Urban/rural China	15-year-old males and females (Obs. 606)	Clinical verifications	Tuberculosis	Biomass/solid fuels use	Positive, insignificant association
Perez-Padilla et al. (1996)	Urban Mexico	> 15-year-old females (Obs. 126)	Multivariate logistic regression	Tuberculosis	Fuels consumption and length of exposure time	Positive association
Perez-Padilla et al. (2001)	Urban/rural India	> 24-year-old females (Obs. 204)	Multivariate logistic regression	Tuberculosis	Fuels/biomass fuel use	Positive association
Kan et al. (2011)	Urban India	> 15-year-old males and females (Obs. 378)	Multivariate logistic regression	Tuberculosis	Fuels/biomass fuel use	Positive association
Gupta et al. (1997)	Urban Benin	> 22-year-old males and females (Obs. 600)	Multivariate logistic regression	Tuberculosis	Fuels/biomass fuel use	Positive association
Garcia-Sancho et al. (2009)	Urban Mexico	> 15-year-old females (Obs. 833)	Multivariate logistic regression	Tuberculosis	Fuels/wood stove for cooking	Positive association
Behera and Aggarwal (2010)	Rural Malawi	15-year-old females (Obs. 768)	Multivariate logistic regression	Tuberculosis	Fuels/biomass fuel use in dry and wet seasons	Positive association
Gninafon et al. (2011)	Urban Mexico	> 40-year-old females (Obs. 83)	Multivariate logistic regression	Tuberculosis	Fuels/biomass fuel use and number of exposure hours	Positive association
Mishra et al. (1999)	Urban/rural India	> 20-year-old males and females (Obs. 422)	Multivariate logistic regression	Tuberculosis	Fuels/biomass fuel use in cooking	Positive association
Sumpter and Chandramohan (2013)	Urban/rural developing countries	Review of research papers (Obs. 12)	Meta-analysis	Tuberculosis	Indoor pollution due to fuels used in cooking	Positive association

Source: compiled by author based on the work of Sumpter and Chandramohan (2013)

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