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Infant mortality rate and nonrenewable energy consumption in Asia and the Pacific: the mediating role of carbon emissions

Bosede Ngozi Adeleye[1,2,3] · **Muhammad Azam**[4] · **Festus Victor Bekun**[5,6]

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Abstract

This study aligns with the 2030 United Nations Sustainable Development Goal 3 which aims to "ensure healthy lives and promote well-being for all at all ages". It contributes to the nascent literature stream on energy-health dynamics by introducing a holistic theoretical model to empirically examine the mediation effect of carbon emissions on the relationship between nonrenewable energy and infant mortality rate. Using an unbalanced panel data on 42 Asia and the Pacific countries from 2005 to 2015 and deploying the structural equation modelling (SEM) approach, the empirical results are surmised as follows: (i) for the full sample, nonrenewable energy indirectly increases infant mortality rate through increasing carbon emissions. In other words, carbon emissions play a partial mediation role between nonrenewable energy and infant mortality rate; and (ii) for the different income groups, carbon emissions show varying mediation effects. For example, the mediation effect of carbon emissions in lower-middle and upper-middle income countries are found to be similar to those of the full sample of countries. Therefore, based on these findings, we conclude that nonrenewable energy is an essential determinant of infant mortality rate. Policy recommendations are put forward.

Keywords Carbon emissions · Infant mortality rate · Per capita income · Nonrenewable energy · Asia

JEL Classification I00 · I10 · I15 · I18 · I19 · N55

Introduction

The drive to maintain a healthy society necessitated the 2030 United Nations Sustainable Development Goal (SDG) 3 agenda, which is to "ensure healthy lives and promote well-being for all at all ages". However, achieving sustainable health is herculean given the environmental factors that pose significant risk against it such as (1) nonrenewable energy (NRE) usage and (2) the emission of carbon dioxide (CO_2). Also, two main health indicators are prevalent in the literature: life expectancy at birth and mortality rate. Life expectancy is "the expectation of how long a new-born person can live on average, assuming that current mortality rates remain unchanged", while infant mortality rate is "the number of children who expires under the age of one for every 1000 live births in a year" (OECD 2017). This study uses infant mortality rate and fills a lacuna in the health-environment literature by interrogating the energy-emissions-health path. It presents some empirical novelties which provoke new perspectives and highlights findings on whether carbon emissions mediate the effect of nonrenewable energy on infant

✉ Festus Victor Bekun
fbekun@gelisim.edu.tr

Bosede Ngozi Adeleye
NAdeleye@lincoln.ac.uk

Muhammad Azam
drazam75@yahoo.com; drazam75@awkum.edu.pk

1 Department of Accountancy, Finance and Economics, University of Lincoln, Lincoln, United Kingdom

2 Lincoln International Business School (LIBS), Lincoln, United Kingdom

3 Centre for Economic Policy and Development Research (CEPDeR), Ota, Nigeria

4 Faculty of Business and Economics, Department of Economics, Abdul Wali Khan University, Mardan, Pakistan

5 Department of International Logistics and Transportation, Istanbul Gelisim University, Istanbul, Turkey

6 Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon

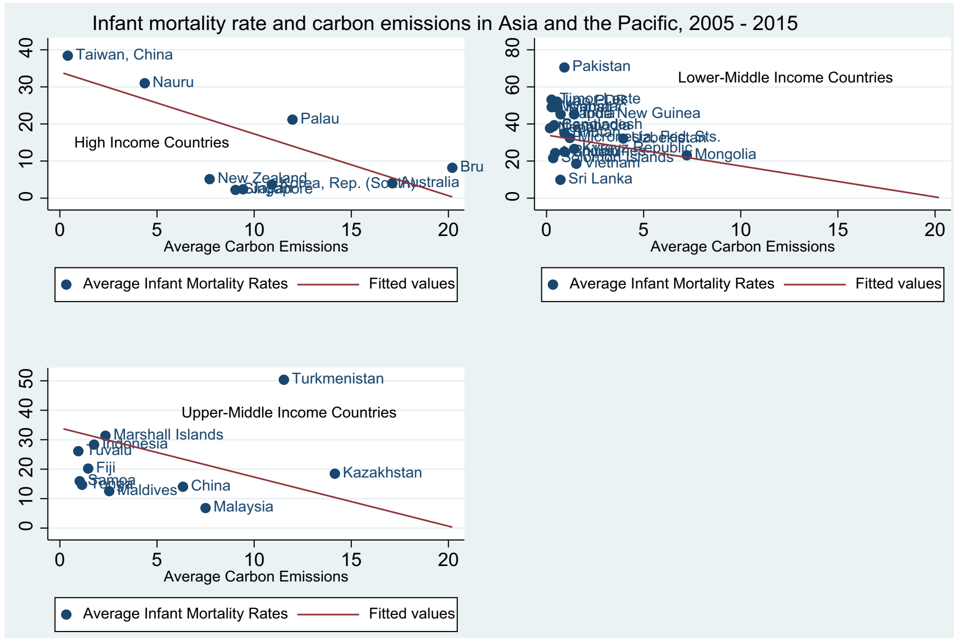

Fig. 1 Infant mortality rates and emissions in Asia and the Pacific, 2005–2015. Source: Authors' Computations from World Bank (2020) World Development Indicators

mortality rate. That is, do carbon emissions play a partial mediation role in energy-health nexus? Conclusions reveal among others that nonrenewable energy is positively associated with infant mortality rate through increasing of carbon emissions. This finding which is sustained along income groups provide significant incursions to the health-environment discourse which serves as the motivation for engaging this study especially from a cross-regional perspective.

Several studies have highlighted the adverse consequences of increasing usage of NRE and CO_2 on the environment (Bailis et al. 2005; Kahia et al. 2016; Asghar et al. 2019; Adeleye et al. 2021; Dabbous and Tarhini 2021; Eregha et al. 2021; Bekun 2022; Jena et al. 2022; Nwani et al. 2022). For instance, energy (renewable and nonrenewable) is an essential "commodity" which plays a critical role in sustaining socio-economic and living standards (EIA 2018; Lelieveld et al. 2019; Radmehr et al. 2021). Examples of renewable energy sources are biomass, hydro (water), wind, solar, and geothermal. These are also known as "green energy" or "clean energy". They are limitless in supply and can be replenished or refilled naturally. Nonrenewable energy (NRE) on the other hand is scarce in supply and cannot be replaced or recycled. Energies in this category are coal, oil, nuclear, and gas (Adeleye et al. 2021). The increasing demand for NRE which intensifies the burning of fossil-fuels such as coal, gas, and oil is driven by the quest to meet the rising anthropogenic demand for goods and services.

In close relation, CO_2 emissions result from using nonrenewable energy sources which pollute the environment and unfavourably affect human health. This indicates that usage of nonrenewable energy can influence human health via environmental pollution (Machol and Rizk 2013). Consequently, this impact leads to a reduction in human capital productivity and therefore causes a decline in socio-economic development. Evidently, environmental contaminants have numerous adverse health effects on humans such as perinatal, cardiovascular, and respiratory illnesses. Others are allergies, rise in stress oxidative, endothelial dysfunction, mental illnesses to mention a few (Kelishadi 2012; Barua et al. 2022; Adeleye et al. 2022a). Indeed, the worsening of environmental quality is explained by the rise in CO_2 which is due to the consumption of NRE resources which can have a destructive effect on the quality of human life (Bouchoucha. 2020; Adeleye et al. 2022b). Prior studies exploring environmental effects on mortality rate have concentrated on pollutants and indicated that exposure to air pollutants is connected to increased risk of human mortality (Krall et al. 2013; Coker et al. 2020; Barua et al 2022; Adeleye et al 2022a).

Figures 1 and 2 show the pattern of infant mortality rates (vertical axis) vis-à-vis carbon emissions (horizontal axis) and nonrenewable energy (horizontal axis). Using average emissions per capita and nonrenewable energy use per capita against deaths per 1000 live births, the scatter plots reveal a negative relation between the two variables across the three income groups, howbeit with some puzzling revelations. High-income countries are clustered at the lowest spectrum of the curve indicating high emitters of carbon dioxide and greater consumption of nonrenewable energy with low mortality rates. Contrarily, lower-middle income countries are huddled on the highest scale of the curve depicting low energy use and low emissions of carbon dioxide but having high mortality rates, while upper-middle income countries

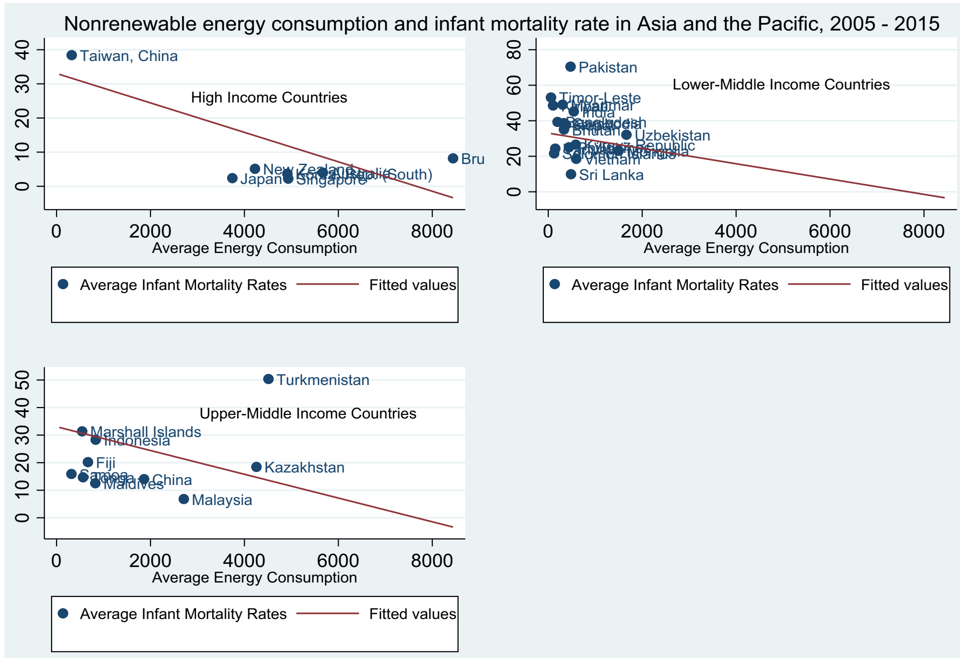

Fig. 2 Infant mortality rates and nonrenewable energy consumption in Asia and the Pacific, 2005–2015. Source: Authors' Computations from World Development Indicators (2020), World Bank

hover in-between the spectrum with somewhat unclear path. Deductively, the plots reveal that mortality rate is the highest in lower-middle income countries while emission/nonrenewable energy use is highest in high-income countries (see Appendix Table A2). These confounding discoveries provide additional rationalization to investigating these relationships and to see if the observed patterns hold empirically across the three groups.

We observed that most studies (see "Literature review and hypothesis development" section) researched the link between environment, economic growth, and public health expenditure. The central contribution of this study is to investigate the mediation effect of CO_2 emissions on the relation between infant mortality rate and NRE consumption in Asia and the Pacific region. The broad objectives of this study are to (1) examine if NRE has a significant impact on carbon emissions, (2) evaluate whether the impact of NRE on mortality rates is significant in the presence of the mediator (carbon emissions), (3) appraise if the impact of the mediator on mortality rates is significant in the presence of NRE, (4) determine if NRE has a significant indirect (mediated) impact on mortality rates, and (5) assess if (1) to (4) significantly differ across income groups. The rest of the study is structured as follows: the "Literature review and hypothesis development" section reviews related studies on the subject under investigation. The "Variables, empirical model, and analytical schema" section presents data, empirical model, and estimation strategy. The "Results and discussions" section interprets and discusses the empirical results. The "Conclusion and policy recommendations" section concludes with policy directions.

Literature review and hypothesis development

The importance of clean and sustainable environment was established in the Kyoto Protocol (1997). The protocol identified GHG emissions, especially carbon dioxide (CO_2) as the leading source of global warming. Moreover, CO_2 emissions from fossil fuels and industrial activities are around 65% of worldwide GHG emissions (IPCC 2014). The significance of energy consumption as documented by Sadorsky (2009) and Bilgili et al. (2016) showed that energy use is a development phenomenon resulting from increase in economic activities, industrialization, and growing urbanization. Also, Smith et al. (2013) showed that energy usage is vital to society and offers numerous benefits despite being the source of environmental degradation (via emissions) and several health risks (Cook et al. 2008). The study added that major health problems occur due to the blazing of solid fuels, biomass, and coal, mostly in the form of work-related health risks and overall air pollution. Furthermore, Campbell-Lendrum and Prüss-Ustün (2019) expounded that the World Health Organization (WHO) has found climate change as one of the biggest health hazards of the twenty-first century with air pollution as the leading environmental health hazard. Several studies showed that the prominent cause of high mortality rate is as a result of environmental degradation from the consumption of NRE resources (Anser et al. 2020; Shobande 2020; Barua et al. 2022). This section undertakes a stylized review of the relevant literature and the development of hypotheses that relate to (i) nonrenewable energy and health outcomes, (ii) nonrenewable energy and carbon emissions, and (iii) nonrenewable energy, carbon emissions, and health outcomes.

Nonrenewable energy and health outcomes

Erdogan et al. (2019) observed that an increase in CO_2 emissions is associated with a decrease in life expectancy at birth by 0.73 percent and an increase in infant mortality rate by 0.70 percent. Anser et al. (2020) studied the influence of greenhouse gas emissions (GHGs), energy utilization, and economic activities on health risks in emerging Asian countries from 1995 to 2018. The empirical evidence showed that fossil fuel usage, GHGs, and natural resource exhaustion are associated with increasing health risks in the long run, while the usage of clean energy and enhancement in per capita income boost health status. Results also reveal that GHG emission is associated with increasing mortality rate and the incidence of respiratory disorders in the short run. Asghar et al. (2019) used the ARDL approach to establish the long- and short-run impact of air pollution, fossils fuels, and diseases on human capital in Pakistan from 1995 to 2017. The study found that NRE is associated with the rise of measles, air pollution, tuberculosis, and mortality rate which consequently affect human capital. Similarly, Shobande (2020) used the Gary Becker hypothesis and the Grossman models to establish that energy predictors have a significant and negative effect on infant mortality rate in 23 African countries from 1999 to 2014. The empirical evidence further revealed that high pollution is associated with increase in mortality rate. Using the generalized method of moments (GMM) technique, Rasoulinezhad et al. (2020) observed that carbon emissions from the use of nonrenewable energy sources is associated with increasing mortality rate in Commonwealth of Independent States (CIS) from 1993 to 2018. From these studies, the general consensus is that nonrenewable energy is positively associated with health outcomes.

Hypothesis 1: Nonrenewable energy usage is positively related to infant mortality rate (proxy for health outcomes).

Nonrenewable energy and carbon emissions

Dogan and Ozturk (2017) studied the effect of real income, NRE, and RE use on CO_2 for the USA from 1980 to 2014. Findings reveal that surges in RE usage alleviate environmental degradation, whereas expansions in NRE consumption inflate CO_2 emissions. The study of Zaidi et al. (2018) shows that RE usage has a statistically insignificant effect on CO_2 in Pakistan from 1970 to 2016, while coal and natural gas are the key contributors to the level of pollution in Pakistan. Also, Hasnisah et al. (2019) found that widespread use of energy from conventional sources such as burning fossil fuels has destructive effect on environmental quality by exacerbating the level of CO_2 emissions in 13 developing Asian countries during 1980 to 2014. Equally, Hanif et al. (2019) found that boost in economic growth and fossil fuel consumption contribute to rising CO_2 emissions which deteriorates the environment in 15 developing Asian countries from 1990 to 2013. Awodumi and Adewuyi (2020) expounded that though NRE use accelerates aggregate production, it is also a key source of CO_2 emissions in top oil-producing African economies over 1980 to 2015. Lastly, Radmehr et al. (2021) found a uni-directional association from RE to carbon emissions in 21 European Union countries from 1995 to 2014. From these studies, the general consensus is that while RE sources have reducing effect on carbon emissions, NRE usage exacerbates emissions.

Hypothesis 2: Nonrenewable energy is positively related to carbon emissions.

Nonrenewable energy, carbon emissions, and health outcomes

Several studies analysed the nexus of energy consumption, carbon emissions, and public health. Given the different scopes and empirical methods, the findings have been diverse and somewhat inconclusive. For instance, Chay and Greenstone (2003) showed that a one percent reduction in total suspended particulates causes a 0.35 percent decrease in infant mortality rate. Gouveia and Fletcher showed that existing ambient levels of air pollution in the city of Sao Paulo, Brazil, are linked with mortality for people above 65 years of age for all non-accidental causes, for cardiovascular and for respiratory illnesses. Also, Ahmad et al. (2016) exposed that CO_2 emissions have an adverse effect on public health in China in the long run. In the same vein, Mutizwa and Makochekanwa (2015) concluded that CO_2 emissions do not have an effect on health status in twelve countries from the Southern African Development Community (SADC) from 2000 to 2008. Likewise, Narayan and Narayan (2008) showed that per capita health spending, per capita income, and CO_2 emissions are co-integrated in eight OECD countries from 1980 to 1999. Equally, Sinha (2014) documented that industrialization enhanced the level of CO_2 emissions in developing countries, and consequently it badly affects the pregnancy outcomes and hygienic states of adolescents. A two-way causal link was observed between changes in infant mortality rate and increase in CO_2 emissions and between gross capital formation and changes in child mortality rate, respectively, from 1971 to 2010. Similarly, Adedotun et al. (2018) examined the influence of environmental degradation measured by PM_{10} on infant mortality rate in Nigeria during 2000 to 2016. The empirical outcomes show that

Table 1 Summary statistics and correlation analysis

Variable	*Summary statistics*				*Correlation analysis*	
	Mean	Std. Dev	Min	Max	lnMINF	lnMU5
$MINF_{it}$	27.074	16.916	2.1	79	1.000	
$MU5_{it}$	33.272	21.715	2.7	99.8	0.998***	1.000
$ENUPC_{it}$	2079.991	2182.923	58.046	9837.447	− 0.712***	− 0.712***
CO_2PC_{it}	4.17	5.123	0.098	24.627	− 0.643***	− 0.655***
$BSAN_{it}$	73.784	24.905	14.131	100	− 0.563***	− 0.581***
$SECF_{it}$	78.246	23.569	26.892	145.888	− 0.690***	− 0.701***

*** denotes statistical significance at the 1% level; *MINF* infant mortality rates, *MU5* under-5 mortality rate, *CO2PC* carbon emissions per capita, *ENUPC* nonrenewable energy per capita, *BSAN* access to basic sanitation, *SECF* female secondary school enrolment, *ln* natural logarithm

Source: Authors' computations

environmental degradation has significant negative effect on infant mortality.

Hypothesis 3: Carbon emissions are positively related to health outcomes.

Hypothesis 4: Carbon emissions mediate the relationship between nonrenewable energy and health outcomes.

Variables, empirical model, and analytical schema

Variables and classifications

This study uses an unbalanced panel data of six variables on 42 countries[1] located in Asia and the Pacific region from 2005 to 2015. The variables are sourced from World Bank (2020) World Development Indicators (WDI). Infant mortality (*MINF*) is the outcome variable, the main explanatory variable is nonrenewable energy per capita (*ENUPC*), and the mediator variable is carbon emission per capita (CO_2PC). We include two control variables: female secondary school enrolment (*SECF*) and access to basic sanitation (*BSAN*). Under-5 mortality (*MU5*) rates are included to test the robustness of the results.

On a priori expectations, nonrenewable energy consumption is expected to yield asymmetric effect on mortality rate. The impact will be positive, if increased use of unfriendly energy sources causes increased environmental pollution and eventually leads to deaths of infants and under-5 children. However, the impact is negative when nonrenewable energy sources are channelled to power health-sustaining outcomes, thereby cutting down deaths of infants and children. The effect of carbon emissions on child mortality is expected to be positive as environmental pollution is hazardous to health. These statements are reinforced by the literature as inundated in the "Literature review and hypothesis development". Education brings enlightenment such that as female secondary education improves, mothers are informed about safer ways of taking care of infants and children. Hence, it is expected that child mortality rates drop since more knowledgeable mothers are expected to understand the essentials of childcare and upbringing better than those who hold little or no education. Likewise, safe drinking water and a better sanitary environment are expected to reduce improve living conditions, increase lifespan, and reduce mortality rate. These assertions are supported by related studies (Shobande 2020; Barua et al. 2022; Adeleye et al 2022a).

We proceed to show the measures of central tendency and correlation among the variables in Table 1. With emphasis on the indicators of interest, the average infant mortality rate for the region is 27.07%, and the standard deviation of 16.92 shows that the countries are widely dispersed from the sample average. Japan shows the lowest in 2013 to 2015 with 2.1, while Pakistan has the highest infant mortality at 79% in 2005. The average under-5 mortality rate is 33.27, while the standard deviation of 21.7 evidence wide deviation from the sample mean. Singapore indicates the lowest under-5 mortality rate at 27% for years 2013 to 2015, while the country with the highest is Pakistan at 99.8% in 2005. The mean of carbon emissions is 4.17 with a standard deviation of 5.12. Nepal consistently shows the lowest emissions per capita from 2005 to 2009 averaging between 0.09 and 0.161, while Brunei shows the highest from 2007 to 2014 averaging between 19.29 and 24.63. Lastly, the sample mean for energy per capita is 2079.99 with a standard deviation of

[1] **High income (11):** Australia, Brunei Darussalam, Hong Kong, Japan, Korea, Rep. (South), Macao SAR, Nauru, New Zealand, Palau, Singapore, and Taiwan. **Lower-middle income (20):** Bangladesh, Bhutan, Cambodia, India, Kiribati, Kyrgyz Republic, Lao PDR, Micronesia, Fed. Sts., Mongolia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Solomon Islands, Sri Lanka, Timor-Leste, Uzbekistan, Vanuatu, and Vietnam. **Upper-middle income (11):** China, Fiji, Indonesia, Kazakhstan, Malaysia, Maldives, Marshall Islands, Samoa, Tonga, Turkmenistan, and Tuvalu.

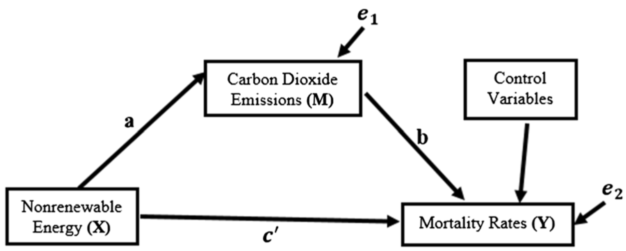

Fig. 3 Mediation modelling of nonrenewable energy, carbon emissions, and mortality rate. Source: Authors' construction

2182.92 which reveals that the countries are widely dispersed. Timor-Leste steadily shows the lowest emissions per capita from 2006 to 2008 averaging between 58.05 and 58.85, while Brunei Darussalam shows the highest from 2006 to 2014 averaging between 6074.57 and 9837.45 (Note: Detailed summary statistics across the income groups is available on request).

The right-hand side of Table 1 details the pairwise correlation, which measures the relative association among the regressors and dependent variable. Using the natural logarithmic transformation of the variables, all the regressors have statistically significant negative relationship with mortality rate. These provide some evidence that as the indices of these regressors increase, mortality rate declines. However, the negative relation between mortality rate, nonrenewable energy, and carbon emissions (which supports Figs. 1 and 2) is somewhat implausible and calls for rigorous econometric analysis (see "Results and discussions" section).

Analytical schema

This study argues that because nonrenewable energy naturally discharges carbon dioxide, methane, and other gasses into the atmosphere, it contributes to changing climate patterns that invariably affect food production, animal ecosystems, human health, and essential biodiversity within habitats. In other words, the planet is heated as more nonrenewable fuel is burned causing adverse health outcomes. Another dimension to this nonrenewable energy-emissions path is that fossil fuel which is one of the sources of nonrenewable energy leads to increase in carbon dioxide emissions in the atmosphere considered to be the primary source of "greenhouse" gas effect that causes environmental degradation with attendant harmful health aftermaths (Adeleye et al. 2021; Barua et al. 2022).

Hence, the conceptual framework in Fig. 3 shows that the impact of nonrenewable energy consumption (X) on mortality rate (Y) is not *somewhat* direct but mediated via a third variable (M). The discourse is probed on whether environmental degradation mediates the impact of nonrenewable energy consumption on mortality rate. That is, does nonrenewable energy consumption exert a significant indirect (mediated) effect on mortality rate? In this energy-mortality rate framework, a third variable is added to the analysis of the initial X → Y relation in order to improve understanding of the connection or to determine if the link is spurious. Mediation analysis is a method to increase information obtained from a research study when measures of the mediating process are available (Judd and Kenny 1981b). A mediating variable improves understanding of such a relation because it is part of the causal sequence of X → M → Y. Such that, nonrenewable energy → carbon emissions → mortality rates (that is, nonrenewable affects emissions and emissions affects mortality rate).

Figure 3 uses the notation most widely applied in mediation modelling (see MacKinnon et al. 2007; Baron & Kenny 1986; Kenny et al. 1998), with ***a*** representing the relation of nonrenewable energy to carbon dioxide emissions, ***b*** representing the relation of carbon dioxide emissions to mortality rates adjusted for nonrenewable energy, and c' the relation of nonrenewable energy to mortality rates adjusted for carbon dioxide emissions. The symbols e_1 and e_2 represent residuals in the carbon dioxide emissions and mortality rate models, respectively. The equations and coefficients corresponding to Fig. 3 are discussed in the "Empirical models" section. For now, note that there is a direct effect relating nonrenewable energy to mortality rate and a mediated effect by which nonrenewable energy indirectly affects mortality rate through carbon dioxide emissions.

Empirical models

As discussed in the "Literature review and hypothesis development" section, supporting empirical evidences (such as Barua et al. 2022; Adeleye et al. 2022a) showcase the links between emissions and health outcomes and between nonrenewable energy and health. This study connects the distinct relationships by conjuring a mediation hypothesis by which carbon emissions arbitrate the impact of nonrenewable energy on infant mortality rate. In other words, attempt is made to evaluate the direct and indirect effects of nonrenewable energy consumption on infant mortality rate using the mediation approach. There are three major approaches to statistical mediation analysis: (a) causal steps, (b) difference in coefficients, and (c) product of coefficients (MacKinnon et al. 2007). This study uses the product of coefficients approach. Following Pei et al (2019), we specify three models:

$$MINF_{it} = \psi_0 + \psi_1 ENUPC_{it} + \psi_2 Z'_{it} + \gamma_t + e_{it} \tag{1}$$

$$CO2PC_{it} = \eta_0 + \eta_1 ENUPC_{it} + \eta_2 Z'_{it} + \gamma_t + \tau_{it} \tag{2}$$

$$MINF_{it} = \alpha_0 + \alpha_1 ENUPC_{it} + \alpha_2 CO2PC_{it} + \alpha_3 Z'_{it} + \gamma_t + v_{it} \tag{3}$$

In the aforementioned three empirical models, Eqs. (1) and (3) are the determinative equations of infant mortality rate, and Eq. (2) is the determinative equation of carbon emissions where ψ_0, η_0, and α_0 are intercepts; *MINF* is the dependent variable measured by mortality rate for infants; *ENUPC* is the independent variable measured by nonrenewable energy per capita; *CO2PC* is the mediator measured by carbon emissions per capita; Z' is a vector of covariates that affect mortality rate (female secondary education and access to basic sanitation); γ_t is the time fixed effect; and e_{it}, τ_{it}, and v_{it} are the random disturbances. In simple terms, $\boldsymbol{\psi}_1$ in Eq. (1) is the coefficient relating the nonrenewable energy to mortality rate; $\boldsymbol{\alpha}_1$ in Eq. (3) is the coefficient relating nonrenewable energy to mortality rate adjusted for the mediator; $\boldsymbol{\alpha}_2$ is the coefficient relating the mediator to mortality rate adjusted for nonrenewable energy; and $\boldsymbol{\eta}_1$ in Eq. (2) is the coefficient relating nonrenewable energy to the mediator, carbon emissions. Equations (1), (2), and (3) which are depicted in Fig. 3 capture the respective $\boldsymbol{c}'$, $\boldsymbol{a}$, and $\boldsymbol{b}$ paths.

The coefficient $\boldsymbol{\psi}_1$ indicates the *total* effect of the nonrenewable energy consumption on mortality rate. The coefficient $\boldsymbol{\alpha}_1$ represents the *direct* effect of the nonrenewable energy consumption on the mortality rate controlling for the influence of carbon emissions. The *indirect*[2] (mediation) effect equates to $\boldsymbol{\eta}_1 * \boldsymbol{\alpha}_2$ using the product coefficient approach, and the total effect is equal to the sum of the mediation effect and direct effect, i.e. $\boldsymbol{\psi}_1 = (\boldsymbol{\eta}_1 * \boldsymbol{\alpha}_2) + \boldsymbol{\alpha}_1$. Note that the mediation equations may be altered to incorporate additional covariates. To check for results robustness, *under-5 mortality rate* is used as the outcome variable to observe if the empirical outcomes are sustained. Lastly, to engage the sub-sample analysis by income groups, the data is categorized into 3 groups of high income, lower-middle income, and upper-middle income countries.

Estimation approach

This paper uses the mediation modelling approach within the structural equation modelling (SEM) framework to address the study objectives. SEM is widely used in social, behavioural, and economic sciences to evaluate linear relationships among variables. Several overviews and variations of SEM can be found in Satorra (1990) and Mackinnon et al. (2007) to mention a few. The mediation modelling technique, on the other hand, handles how the predictor variable *X* impacts the outcome variable *Y* (Hayes 2013; Baron and Kenny 1986). Hojnik et al. (2018) explain that mediation equations specify the existence of a significant intervening mechanism (in our case, carbon emissions) between the predictor variable (nonrenewable energy consumption) and the outcome variable (infant mortality rate). As such, the mediator variable (carbon emissions) accounts for a significant proportion of the relationship between the nonrenewable energy and the outcome variable.

Given the above, the data is analysed using the structural equation *sem* routine in Stata version 16. SEM is chosen because of its precision for producing unbiased estimates of mediation impacts (Cheung and Lau 2008). Adapting the two-step method recommended by Anderson and Gerbing (1988), the structural and regression models are estimated in separate steps. First, a structural model representing the hypothesized structural relationship between nonrenewable energy and carbon emissions is evaluated (Eq. 2). Second, the regression model is analysed to test the adequacy of the hypothesized relation (Eq. 3). In addition, based on the non-normal distribution of the data, the mediation (indirect) effect is tested using the Satorra-Bentler robust standard error technique (Satorra 1990). This approach is justified in obtaining parameter estimates such as fitting the model and evaluating the estimates' sampling variability as well as the null distribution of test statistics. Lastly, the goodness-of-fit of both models is evaluated. To know if the data fits well with the hypothesized model, three critical fit indices widely used in structural equation modelling analysis are applied: the comparative fit index (Bentler 1990), Tucker–Lewis index (Bentler and Bonett 1980; Tucker and Lewis 1973), and root mean square error of approximation (Steiger 1990). RMSEA is an absolute fit index, in that it assesses how far a hypothesized model is from a perfect model. On the contrary, CFI and TLI are incremental fit indices that compare the fit of a hypothesized model with that of a baseline model (i.e. a model with the worst fit).

Results and discussions

This section presents empirical findings which fill essential gaps in the health-energy literature on Asia and the Pacific by showcasing findings on whether carbon emissions mediate the impact of nonrenewable energy on mortality rate and whether this impact differs across income groups. Estimations begin with the structural and regression models in Table 2 followed by the decomposition of effects and diagnostics in Table 3, while Table 4 summarizes the validation of the hypotheses. Corresponding robustness results are available on request.

[2] Mediation effect exists if the coefficients of the nonrenewable energy ($\boldsymbol{\eta}_1$) and carbon emissions ($\boldsymbol{\alpha}_2$) are statistically significant.

Table 2 Empirical results (full sample and income groups)

Variables	Main [1]	High income [2]	Lower-mid inc [3]	Upper-mid inc [4]
Structural model: Dep. Var: ln*CO2PC*				
$lnENUPC_{it}$	1.1309***	1.2313***	1.0841***	1.0830***
	(32.59)	(135.81)	(10.88)	(28.05)
Constant	− 7.1204***	− 8.1194***	− 6.8692***	− 6.5135***
	(− 26.77)	(− 117.27)	(− 10.71)	(− 21.51)
Regression model: Dep. Var: ln$MINF_{it}$				
$lnENUPC_{it}$	− 0.5222***	0.2588	− 0.0238	− 0.7859**
	(− 8.02)	(0.82)	(− 0.21)	(− 2.21)
$lnCO2PC_{it}$	0.0878*	− 0.4708*	0.1136**	0.5749**
	(1.76)	(− 1.90)	(2.04)	(2.08)
lnSECFit	− 0.8190***	0.6938**	− 0.7392***	0.9073
	(− 7.96)	(2.53)	(− 6.57)	(1.52)
$lnBSAN_{it}$	0.0309	− 23.6148***	− 0.1588	− 2.0540***
	(0.24)	(− 19.63)	(− 1.31)	(− 6.32)
Constant	9.9347***	105.8284***	7.4410***	12.7425***
	(12.19)	(20.25)	(8.77)	(5.00)
Observations	171	171	171	171
Log-likelihood	− 561.91	− 142.4754	− 142.4754	− 142.4754
Wald test ($lnCO2PC_{it}$)	1062.16***	18,445.12***	118.37***	786.65***
Wald test ($lnMINF_{it}$)	334.46***	1709.94***	94.12***	150.48***

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively; estimations with Satorra-Bentler standard errors; *ln* natural logarithm, *MINF* infant mortality rates, *MU5* under-5 mortality rate, *CO2PC* carbon emission per capita, *ENUPC* nonrenewable energy per capita, *SECF* female secondary school enrolment, *BSAN* access to basic sanitation

Source: Authors' computations

Table 3 Decomposition of effects and diagnostics, main results

Nonrenewable energy consumption	Full sample Standardized	High Standardized	Lower-mid Standardized	Upper-mid Standardized
Direct effects	− 0.522***	0.2588	− 0.024	− 0.786**
z stat	(− 8.02)	(0.82)	(− 0.21)	(− 2.21)
Mediation effects	0.099*	− 0.579*	0.123**	0.623**
z stat	(1.76)	(− 1.89)	(2.25)	(2.15)
Total effects	− 0.423***	− 0.321***	0.099	− 0.163*
z stat	(− 10.08)	(− 14.80)	(1.24)	(− 1.75)
Diagnostics/goodness-of-fit	Full sample	Income groups		
RMSEA	0.016	0.018		
Comparative fit index (CFI)	0.994	0.981		
Tucker-Lewis index (TLI)	0.981	0.934		
Standardized root mean squared residual	0.018	0.044		
Coefficient of determination (CD)	0.922	0.915		

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively; estimations with Satorra-Bentler standard errors; *RMSEA* root mean squared error of approximation

Source: Authors' computations

Full sample and income group results, main analysis

From the structural model in the upper part of Table 2, the coefficient of *ENUPC* is positive and statistically significant at the 1% level across all model specifications. This indicates that a percentage change in nonrenewable energy is significantly associated with increasing carbon emissions by 1.13, 1.23, 1.084, and 1.083 in the full

Table 4 Hypothesis validation

Hypotheses	FS	HI	LMI	UMI
Hypothesis 1**:** Nonrenewable energy is positively related to infant mortality rate (direct effect)	R	PS	PR	R
Hypothesis 2**:** Nonrenewable energy is positively related to carbon emissions	S	S	S	S
Hypothesis 3**:** Carbon emissions are positively related to infant mortality rate	S	R	S	S
Hypothesis 4**:** Carbon emissions mediate the relationship between nonrenewable energy and infant mortality rate (direct/indirect effect)	S	R	S	S

FS full sample, *HI* high income, *LMI* lower-middle income, *UMI* upper-middle income, *R* rejected, *PR* partially rejected, *S* sustained, *PS* partially sustained

Source: Authors' compilation

sample, high, lower-middle, and upper-middle income countries, respectively, on average, *ceteris paribus*. This outcome aligns with related studies (Awodumi and Adewuyi 2020; Adeleye et al. 2021). From the regression model with *MINF* as the dependent variable, the coefficient of *ENUPC* is negative and statistically significant at the 1% and 5% levels for the full sample and upper middle-income countries. This suggests that a percentage change in nonrenewable energy is significantly associated with a decrease in infant mortality rate by 0.52 and 0.79 per cent for the full sample and upper-middle income countries, respectively, on average, *ceteris paribus*. This outcome contradicts Anser et al. (2020) who found a long-run positive relation. The study used fossil energy per capita as the proxy for nonrenewable energy on selected emerging economies in Asia and showed that as more fossil energy is consumed, it exerts a debilitating effect on mortality rate and a rise in the reported cases of respiratory diseases which are the proxies for health outcomes. However, from Asghar et al. (2019) who used coal and oil consumption as proxies of nonrenewable energy, the study showed that nonrenewable (using oil consumption) has a significant negative short- and long-run effect on human capital in Pakistan, while a significant positive short- and long-run effect is realized when coal consumption is used as proxy.

Also, the coefficient of *CO2PC* is negative and statistically significant at the 10% level for high-income countries while positive and statistically significant at the 10% and 5% levels for the full sample, lower-middle, and upper-middle income countries. This shows that while emissions are negatively associated with mortality rate in high-income countries, the reverse is the case for other specifications. The negative outcome which fits Fig. 1 supports Adeleye et al. (2023), while the positive outcomes align with Rasoulinezhad et al. (2020). On the control variables, basic sanitation and female secondary education evidence mortality-decreasing properties for the full sample and lower-middle income countries (Shobande 2020), but education exacerbates mortality rate in high-income countries. For the most part, these findings align with a priori expectations.

Total, direct, and indirect (mediation) effects

The results shown in the upper part of Table 3 decompose the total effects into direct and mediation effects. The direct effects are represented by the coefficient of *ENUPC* on mortality rate as interpreted in the "Full sample and income group results, main analysis" section. This paper's contribution is highlighted by its findings on the mediation effects. We show that the mediation effect is negative and statistically significant at the 10% level for high-income countries while positive and statistically significant at the 10% and 5% levels for the full sample, lower-middle, and upper-middle income countries. This implies that nonrenewable energy indirectly reduces mortality rate in high-income countries but increases for the full sample, lower-middle, and upper-middle income countries. These are significant incursions into the health-environment literature. The total effect is the sum of the direct and indirect effects with the intuitive interpretation that overall, nonrenewable energy exerts mortality-reducing outcomes in three out of four models supporting Fig. 2, in hindsight.

For the diagnostics, having deployed the Satorra-Bentler robust standard errors, the goodness-of-fit of the models is evaluated. Hu and Bentler (1999) suggested the following criteria for a good model fit: RMSEA <0.06, CFI and TLI >0.95, and our models align with these thresholds. The CD mirrors the R-squared and indicates that about 92% variation in mortality rate is explained by the regressors. Overall, we conclude that the specified models are not statistically different from the hypothesized models. To test the robustness of our results, the dependent variable is replaced with under-5 child mortality rate, and the outcomes are available on request. For the most parts, the results are not significantly different from those of Tables 2 and 3.

Hypothesis validation

The summary of the regression analyses of the four hypotheses tested in the study is shown in Table 4. Hypothesis 1 is rejected for the full sample and upper-middle income countries while partially sustained[3] and partially rejected[4] for high-income and lower-middle income countries. Hypothesis 2 is sustained for all. Hypothesis 3 is rejected for high-income countries but sustained for others. Lastly, hypothesis 4 which is the contribution of this study is rejected for high-income countries but sustained for others.

Conclusion and policy recommendations

The nexus between energy-emissions, emissions-health, and energy-health has been well documented in the extant literature with varying and inconclusive outcomes. Though the energy-health nexus has been explored, this study submits that to the best of our knowledge, no single study to date has explored the mediating role of carbon emissions in the relationship between nonrenewable energy and mortality rate for Asia and the Pacific bloc. Therefore, the present study fills this research gap. We contribute to the emerging literature stream on energy-emissions-health dynamics by introducing a theoretical model to empirically examine the mediation effect of carbon emissions on the relationship between nonrenewable energy and mortality rate. Using an unbalanced panel data on Asia and the Pacific countries from 2005 to 2015 and deploying the structural equation modelling (SEM) approach, the results are surmised as follows: (i) for the full sample of countries, nonrenewable energy potentially indirectly increases infant mortality rate through increasing carbon emissions. In other words, carbon emissions play a partial mediation role between nonrenewable energy and infant mortality rate; and (ii) for the different income groups, carbon emissions show varying mediation effects. For example, the mediation effect of carbon emissions in lower-middle and upper-middle income countries are found to be similar to those of the full sample. Therefore, based on these findings, we conclude that nonrenewable energy is an essential determinant of infant mortality rate.

These results somewhat provide argument for the importance of using clean energy resources contrary to nonrenewable energy which indirectly exacerbates infant mortality rate through growing carbon emissions. Past studies have established that environmental pollution is a leading cause of respiratory ailments and mortality rate. Based on these empirical findings, recommendations are in favour of fostering clean energy production in order to improve both the environment and human health. That is, adoption of clean energy approaches may be effective in reducing environmental concerns caused by GHG emissions. In the same vein, there is a need for policy improvements regarding the use of nonrenewable energy sources in order to protect the environment and human health via reducing the production of carbon emissions. Moreover, since nonrenewable energy is indirectly associated with increasing infant mortality rate through increasing carbon emissions, it becomes imperative that measures towards energy transition to renewable energy sources need to be pursued by the various Asian governments and stakeholders in the heath sector. This is because wind, solar, and hydroelectric systems generate electricity with no associated air pollutants. In other words, adopting environmental quality policies will further reduce the incidence of infant mortality rate in these countries. Leveraging on the well-established insights on the mediating role of carbon emissions on the energy-health nexus in Asia and the Pacific countries, future studies can explore other emerging or developed blocs or countries while controlling for socio-economic indicators (such as renewable energy, per capita income, and health expenditures) that affect health outcomes (such as infant and under-5 mortality rate and life expectancy at birth).

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Data availability Data will be made available upon request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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[3] Partially sustained = coefficient is positive but statistically not significant.

[4] Partially rejected = coefficient is negative but statistically not significant.

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