



Analyzing the impact of access to electricity and biomass energy consumption on infant mortality rate: a global perspective

Nabila Asghar¹ · Muhammad Asif Amjad² · Hafeez ur Rehman²

Received: 12 April 2022 / Accepted: 6 November 2022 / Published online: 22 November 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract

Conserving the lives of newborns has been a long-standing issue around the world, where 2.4 million babies die in the first month of the life. The literature indicates that the important challenges of social development goals around the globe include affordable and easy access to electricity, promotion of sustainable economic development, and provision of better social services and creation of job opportunities which help in reducing infant mortality rate. This calls for the need to probe into this matter minutely and brings up the ways for reducing the infant mortality rate. The present study is an attempt to analyze the impact of rural and urban electrification and biomass energy consumption on infant mortality rate for the period 1990–2020 using the Panel Quantile Regression (PQR) approach. The results of the study show that in both developed and developing countries, biomass energy consumption has positive impact on infant mortality rate, while rural and urban electrification has proposed the inverted U-shaped relationship with infant mortality in different quantile groups. It is also concluded that few developing countries are failed to achieve the maturity of the inverted U-shaped curve while all developed countries have achieved at the maturity stage. This study recommended that for reducing the infant mortality rate, the world should discourage the use of biomass energy and promote the affordable and easy access to electricity on priority basis.

Keywords Infant mortality rate · Biomass energy consumption · Rural and urban electrification · Panel Quantile Regression

Introduction

In this modern age, energy is regarded as the most important sector of developing and developed economies because all economic activities heavily depend upon it. Without energy, a country cannot run the factories and cities that provide jobs, homes, and goods, which are the major sources of a comfortable life and amusement particularly

in the emerging economies (Amjad et al. 2021a). The future challenges faced by the world include energy crises, economic hardship, inequalities, and climate vulnerability due to climate change (Amjad et al. 2021b; Berrod et al. 2019). Presently, most of the developing countries face energy poverty due to inability to access the modern energy services, easy access to electricity and clean cooking facilities (IEA 2017). The energy poverty is usually caused by high energy prices, energy inefficient houses and appliances, and lower income level (Marí-Dell’Olmo et al. 2017; Fahmy et al. 2011). Energy poverty is not confined to the limited availability and accessibility to electricity, but also, it is related to the quality of life. The absence of modern energy services adversely affects the human well-being. The availability and access to clean energy are pivotal for human well-being and better quality of life (Shobande 2020).

WHO (2007) describes that the minimum room temperature should be 21 °C for healthy conditions. However, it is not easy to provide adequate access to electricity, cooking, and heating facilities globally (Falk et al. 2021; Buzar 2016). International Energy Agency (IEA) pointed out that about

Responsible Editor: Philippe Garrigues

✉ Hafeez ur Rehman
hafeez.rehman@umt.edu.pk

Nabila Asghar
nabeela.asghar@ue.edu.pk

Muhammad Asif Amjad
f2020330007@umt.edu.pk

¹ Department of Economics, Division of Management and Administrative Science, University of Education, Lahore, Pakistan

² Department of Economics and Quantitative Methods, University of Management and Technology, Lahore, Pakistan

96% of the urban population and 85% of the rural population have access to electricity. Mostly, people residing in African countries do not have complete access to electricity (IEA 2019). The energy progress report (2021) describes that significant improvement had been observed in the last decade in terms of access to electricity but this progress is unequal across the regions. Although more than one billion people worldwide have access to electricity by the past decade, but the financial impact of COVID-19 has made the cost of basic electricity services unbearable for an additional 30 million people and majority of them belongs to African region (Amjad et al. 2021c). World Development Report (2019) mentioned that about 87% people live in rural areas in African region and one out of three people face lack of access to electricity especially in Sub-Saharan African countries. Majority of the people in this region depend on traditional biomass (woods, animal dung, and agriculture residues) and coal for energy requirements (Nikus and Wayessa 2021).

According to WHO Report (2020), more than half of the global population (52%) is dependent on biomass fuels and more than 2.4 billion people residing in the third-world countries rely directly on biomass consumption. They use biomass inefficiently in the open-fire cookstoves for cooking and flame lamps for lighting their

houses (Coffey et al. 2021). The biomass consumption in the open-fire cookstove produces smoke that contains human health damaging particles (Maher et al. 2021). It also generates PM10 and other toxic chemical gasses such as hydrocarbons, free radicals, carbon monoxide, and oxygenated organics that cause indoor pollution (Pope et al. 2010). The environmental degradation and smoke from solid fuels spread various diseases such as acute respiratory infections, pneumonia, chronic lung diseases, tuberculosis, cancers, cardiovascular diseases, and cataracts (Pope et al. 2010; Dherani et al. 2008). These diseases mostly affect the health of the women, who cook food and stay in this dangerous environment longer along with their infants (Odo et al. 2021; James et al. 2020; Adaji et al. 2019). This indicates that indoor pollution is the most dangerous killer in developing countries. Chakraborty and Mondal (2021) pointed out that about 1.6 million people die from the indoor pollution each year and half of these deaths occurred among infants under the age of 5 years. In developing countries, indoor pollution causes high infant mortality rate (Rana et al. 2021). Figure 1 shows the deaths from indoor pollution, and it can be observed that African and South Asian countries particularly face high deaths due to lack of access to electricity. While in other countries, majority of the people have easy access

Fig. 1 Flow chart of the theoretical model

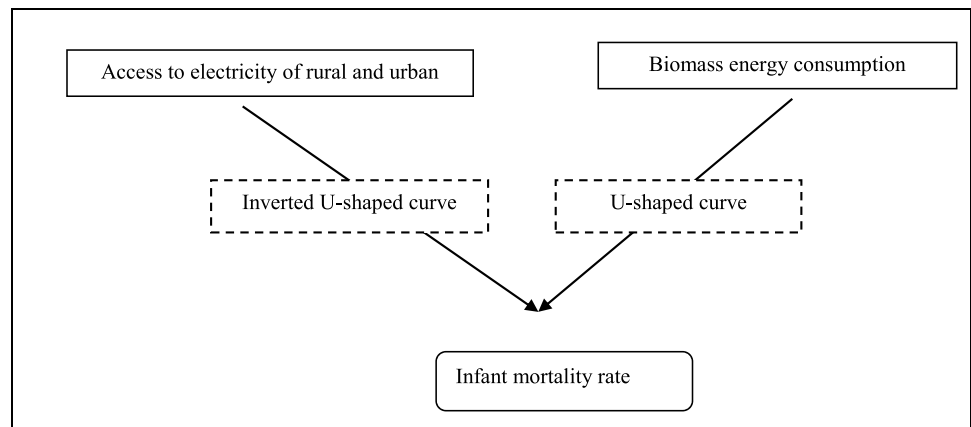


Table 1 Description of the variables

Symbol	Indicator	Units
IMR	Infant mortality rate	Per 1000 live births
ACER	Access to the electricity, rural population	% of rural population
ACEU	Access to the electricity of the urban population	% of urban population
CRW	Combustible renewables and waste	% of total energy
URPOP	Urban population	% of total population
EDU	School enrollment, preprimary	% gross
SERV	Services, value-added	% of GDP
INDU	Industrialization, value-added	% of GDP

Table 2 Descriptive statistics

Variable	Developing countries					Developed countries				
	Obs	Mean	Std. Dev	Min	Max	Obs	Mean	Std. Dev	Min	Max
LNIMR	1457	3.751	0.658	1.775	5.093	2263	2.240	0.846	0.531	4.333
LNAER	1416	3.190	1.408	-5.969	4.944	2261	4.501	0.365	0.342	5.185
LNAEU	1442	4.288	0.530	-0.242	5.263	2263	4.594	0.047	4.025	4.751
LNCRW	1452	2.617	2.311	-5.082	4.542	2255	1.175	1.882	-7.358	4.234
LNPREP	1312	2.840	1.329	-2.765	4.912	2263	4.078	0.679	-1.232	5.118
LNIND	1377	3.227	0.413	-0.093	4.287	2263	3.307	0.300	2.301	4.440
LNSER	1364	3.797	0.225	2.387	4.520	2262	4.023	0.208	1.167	4.384
LNURPOP	1457	15.972	1.255	12.965	19.993	2263	15.817	1.592	12.492	20.58

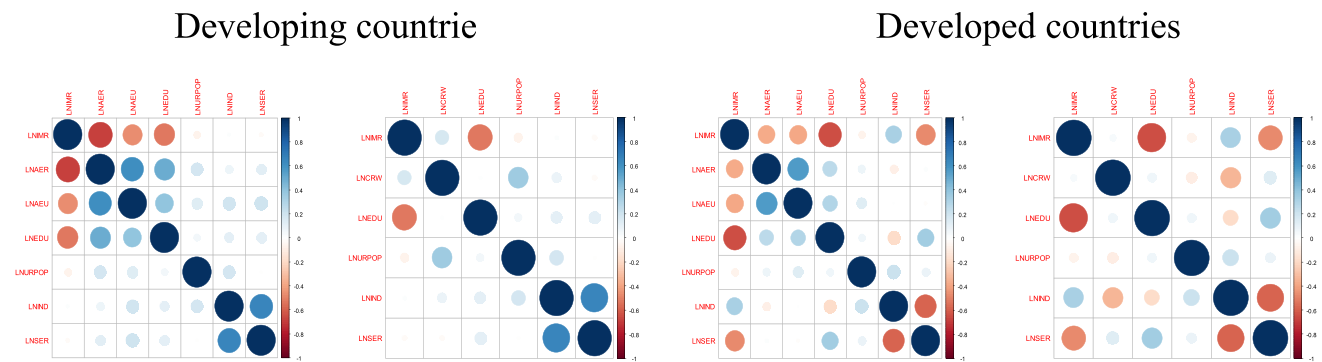


Fig. 2 Correlation plots

to electricity who enjoy good health, get better education, and obtain massive food production, protect climate change, and get benefits of high economic growth.

No doubt all members of the society are not equally vulnerable to energy poverty. Presently, energy has become highly important for health and other socio economic aspects of the human life. Women and children are often the most affected by the energy poverty. Furthermore, it has been observed that the Gender Inequality Index (GII) is generally higher for the countries having widespread problems of energy poverty (UNDP 2016). This relationship is quite understandable as the collection of biomass in developing areas is usually performed by women, who also spend more time in cooking food using biomass energy (Zubi et al. 2019).

The infant mortality rate is highly correlated with the responsibilities and facilities available to women. The affordable and easy access to electricity to household women enables them to spend less time and effort in the collection of biomass and pay more attention to their children’s health (Enyew et al. 2021). Furthermore, the absence of easy access to safe drinking and sanitation water forces the women to carry pitcher of water on their heads and travel long way on foot. In some areas, the women use manual hand pumps to get drinking and

sanitation water. The non-availability of affordable electricity makes the women to wash clothes by hands. The easy access to electricity may make it easy for them to get drinking and sanitation water and use electric washing machines which may improve their health and enable them to get better jobs and invest more in health of their children (Nano 2021).

The improvement in quality of life and the provision of better health facilities depend on easy access to electricity as modern hospitals use electricity for lighting, temperature control, and continuous supply of water and proper functioning of medical

Table 3 Variance inflation factor (VIF)

Variable	Developing countries		Developed countries	
	VIF	1/VIF	VIF	1/VIF
LNAER	3.050	0.328	1.890	0.530
LNAEU	2.110	0.474	1.880	0.532
LNCRW	1.600	0.624	1.290	0.773
LNEDU	1.540	0.648	1.400	0.713
LNSER	1.250	0.800	2.270	0.440
LNURPOP	1.170	0.852	1.170	0.858
LNIND	1.140	0.877	2.450	0.409
Mean VIF	1.70		1.760	

Table 4 Detail results of the Panel Quantile Regression (PQR) of developing countries

	Model 1			Model 2		
	Lower infant mortality	Middle infant mortality	Higher infant mortality	Lower infant mortality	Middle infant mortality	Higher infant mortality
LNAER	0.435* (0.032)	0.361* (0.029)	0.197* (0.038)			
LNAER ²	−0.134* (0.005)	−0.120* (0.005)	−0.091* (0.006)			
LNAEU	0.093 (0.146)	0.449* (0.133)	0.913* (0.174)			
LNAEU ²	−0.021 (0.023)	−0.056* (0.021)	−0.133* (0.027)			
LNCRW				0.101* (0.007)	0.086* (0.008)	0.068 (0.009)
LNCRW ²				0.013* (0.003)	0.023* (0.003)	0.026 (0.004)
LNEDU	−0.139* (0.010)	−0.101* (0.009)	−0.092* (0.011)	−0.232* (0.013)	−0.177* (0.014)	−0.114 (0.017)
LNURPOP	0.135* (0.009)	0.113* (0.008)	0.108* (0.010)	0.057* (0.013)	0.023*** (0.013)	0.010 (0.016)
LNIND	−0.157* (0.028)	−0.218* (0.025)	−0.302* (0.033)	−0.103** (0.043)	−0.200* (0.044)	−0.098 (0.054)
LNSER	−0.247* (0.052)	−0.361* (0.047)	−0.557* (0.062)	−0.647* (0.080)	−0.620* (0.082)	−0.475 (0.101)
_CONS	3.452* (0.359)	5.478* (0.326)	7.433* (0.427)	5.579* (0.406)	6.392* (0.418)	5.842 (0.511)
Pseudo R2	0.543	0.506	0.410	0.418	0.352	0.270
No. of observation	1207	1207	1207	1230	1230	1230

*, **, and *** present the level of significance at 1%, 5%, and 10%, while standard error is presented in parenthesis

equipment. The need for electrification has increased in recent emergency of COVID-19 to run the medical equipment and better sterilized clinics which make women to give birth safely (WHO 2020).

The present study will try to achieve the few objectives to explore the nexus between access to electricity and biomass consumption on infant mortality rate. The first objective is to examine the role of rural and urban electrification on infant mortality rate. The second objective is to explore the impact of biomass energy consumption on infant mortality rate.

The present study is very significant because in the previous literature, there are not many studies exploring the impact of rural and urban electrification and biomass consumption on infant mortality in developed and developing countries. This study is following the novel econometric approach PQR of different groups of infant mortality rates by using the non-linear analysis. Apart from this study, Sial et al. (2022) examined the non-linear impact of energy consumption on infant mortality rate.

Literature review

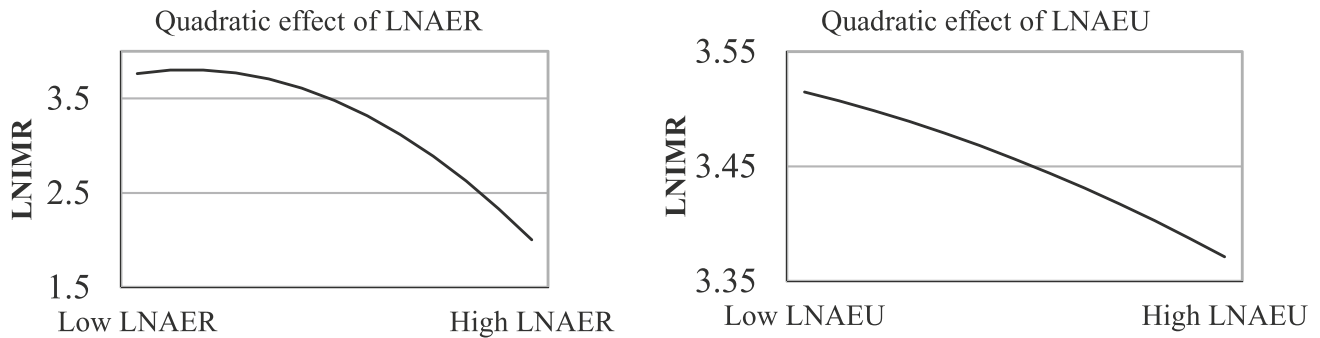
Several studies have explored that climatic pollution is the major cause of infant mortality rate (Han et al. 2021). Fossil fuel consumption is considered the major contributor of environmental pollution in the atmosphere. Sial et al. (2022) found the fossil fuel increases infant mortality rate due to massive air pollution. The present study will examine the impact of access to electricity and biomass consumption

on the infant mortality rate. Access to electricity is considered the clean energy that plays an influential role to control environmental degradation. Furthermore, it also plays a significant contribution to economic development, health, and other socio-economic aspects.

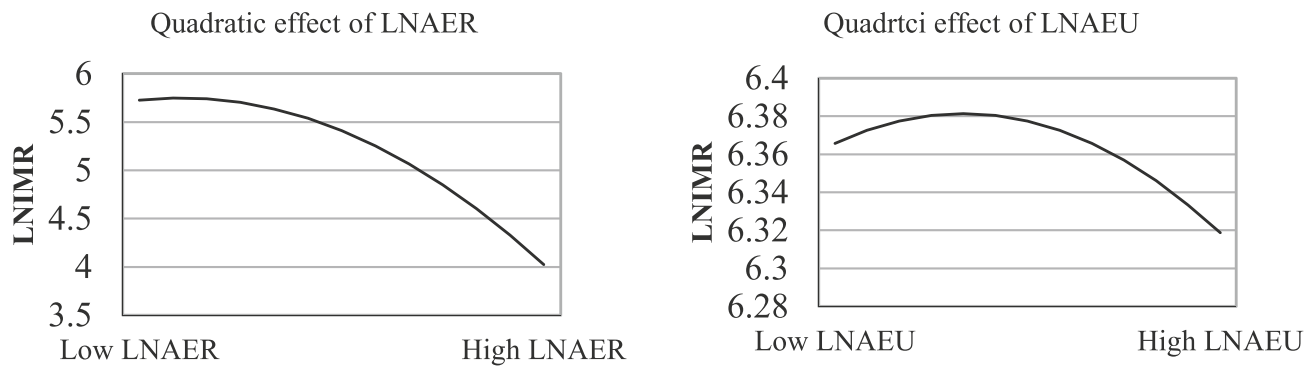
There are numerous literatures which examined the access of electricity on the health sector. The health indicators include infant mortality rate, incidence of malaria, deaths, and acute respiratory diseases. Electrification helps to decline infant mortality rate (Sule et al. 2022; Shobande 2020). Provision of electricity improves the health quality by using modern health care technologies that decline infant mortality rate. Mohammed and Akuoko (2022) analyzed the access to electricity of different infant mortality groups in Ghana. The study explored that in low incidence of infant mortality group, increase in the access to electricity reduces infant mortality, while on the other hand, in high mortality region, improvement of electricity has no impact on infant mortality rate. Ani (2021) pointed out that electrification is indispensable for operating the modern healthcare technologies which reduces infant mortality rate in Nigeria. Ouedraogo et al. (2021) explored that easy access to electricity declined mortality rate under 5-year children, crude death rates, and incidence of malaria in 24 Sub-Saharan African countries. Home births without access to electricity have more risk of death compared to planned hospital births (Dendup et al. 2018). Rutstein (2002) tries to find the factors associated with infant mortality rate in developing countries. The study concludes that easy access to electricity may reduce the infant mortality rate.

Many researchers used access to electricity as the energy poverty. Banerjee et al. (2021) point out that an

Lower infant mortality rate



Middle infant mortality rate



High infant mortality rate

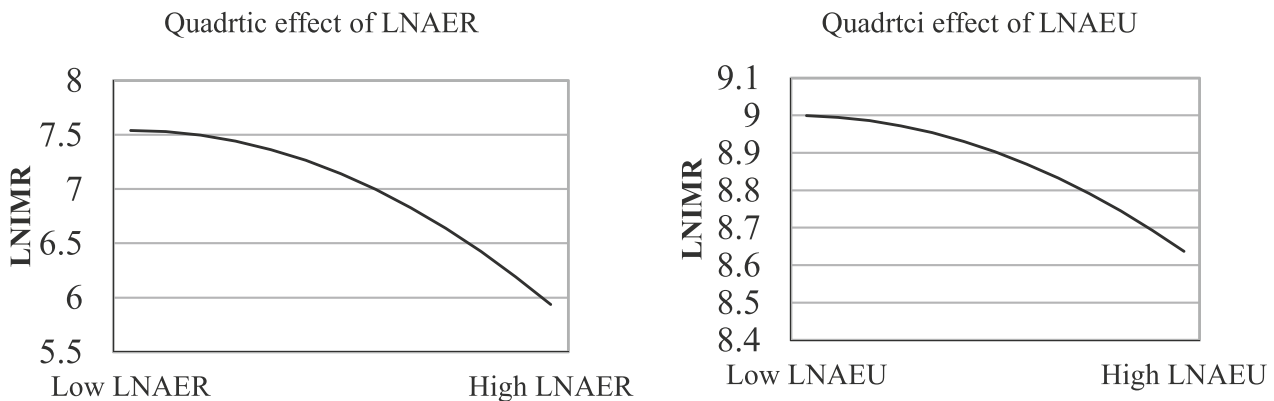


Fig. 3 Quadratic effects of LNAER and LNAEU of developing countries

effort for reducing energy poverty may improve education and health outcomes. Nawaz (2021) explores the impact of multidimensional energy poverty on multidimensional health and climate change deprivation. The study concludes that energy poverty is positively

associated with health poverty in Pakistan. Oliveras et al. (2021) analyze the impact of energy poverty on well-being and health of children. The study concludes that energy poverty has strong correlation with the poor health of children.

Table 5 Cut-off value of developing countries

	Lower infant mortality	Middle infant mortality	Higher infant mortality	Middle infant mortality	Higher infant mortality
	LNAER			LNAEU	
Level coefficients	0.435	0.361	0.197	0.449	0.913
Squared coefficients	−0.134	−0.120	−0.091	−0.056	−0.133
Cut-off values	1.623	1.504	1.082	4.009	3.432
Antilog of cut-off values	5.380	4.756	3.072	63.829	35.108

Table 6 PQR results of developed countries

	Model 1			Model 2		
	Lower infant mortality	Middle infant mortality	Higher infant mortality	Lower infant mortality	Middle infant mortality	Higher infant mortality
LNAER	2.436* (0.264)	2.584* (0.202)	1.408* (0.244)			
LNAER ²	−0.419* (0.042)	−0.456* (0.032)	−0.320* (0.038)			
LNAEU	2.466* (0.881)	2.023* (0.003)	2.999* (21.186)			
LNAEU ²	−0.525* (0.009)	−1.227* (0.073)	−2.096 (2.388)			
LNCRW				0.040* (0.010)	0.058* (0.010)	0.092* (0.010)
LNCRW ²				−0.015* (0.004)	0.009** (0.004)	0.027* (0.004)
LNEDU	−0.427* (0.028)	−0.524* (0.021)	−0.526* (0.026)	−0.677* (0.028)	−0.658* (0.030)	−0.845* (0.029)
LNIND	0.027 (0.078)	−0.016 (0.060)	−0.140*** (0.072)	0.336* (0.085)	0.276* (0.089)	0.394* (0.087)
LNSER	−1.529* (0.114)	−1.824* (0.088)	−1.884* (0.106)	−1.037* (0.118)	−1.377* (0.123)	−1.017* (0.121)
LNURPOP	0.013 (0.011)	−0.015*** (0.008)	−0.023** (0.010)	−0.001 (0.011)	−0.027** (0.012)	−0.054* (0.011)
CONS	−5.935* (0.614)	−4.022* (0.718)	−4.976* (0.864)	7.695* (0.652)	9.833* (0.685)	9.525* (0.671)
Pseudo R ²	0.374	0.438	0.429	0.294	0.346	0.354
No. of observation	2260	2260	2260	2254	2254	2254

*, **, and *** present the level of significance at 1%, 5%, and 10%, while standard error is presented in the parenthesis

More than half of the world’s population has been living in rural areas which face lack of infrastructure, shortage of drinking and sanitation water, and affordable access to electricity. Moner-Girona et al. (2021) examined the benefits of electricity on medical equipment in rural communities in Sub-Saharan African countries. The study explored that clean and reliable photovoltaic renewable electricity facilitates the rural health sector. Chen et al. (2019) analyzed the micro level study in rural areas of Gujarat India. The study concluded that the rural electrification increased the health service utilization, health information, and health facilities through availability of essential equipment and devices. Fujii et al. (2018) explore the association of electrification and children’s nutrition in rural areas of Bangladesh during 2000–2014. The study concludes that electrification has a positive association with nutrition of small children.

Poor economic conditions and lower employment opportunities to the rural population motives them to migrate to the urban areas. To fulfill the consumption requirement of

the urban population needs energy which unfortunately it is accomplishing with the fossil fuels consumption. Wang (2018) pointed out that urban transportation and industrialization running by the fossil fuels is considered the major factor of environmental degradation which badly affects the health sector. Tripathi (2021) identified that urbanization badly damage the health of infants which caused infant mortality.

The households facing lack of access to electricity rely on biomass energy consumption. Bakehe (2021) conducted micro level household data and evaluated that the household that relies on biomass energy resources like woods, dank cakes, and fossil fuels causes different acute respiratory diseases and illness which badly affect the women health. Nesterovic et al. (2021) pointed out that lack of access to electricity forces the people to rely heavily on biomass and non-renewable energy resources which emit excessive CO₂ and cause indoor pollution which is highly dangerous for the health. Yousaf et al.

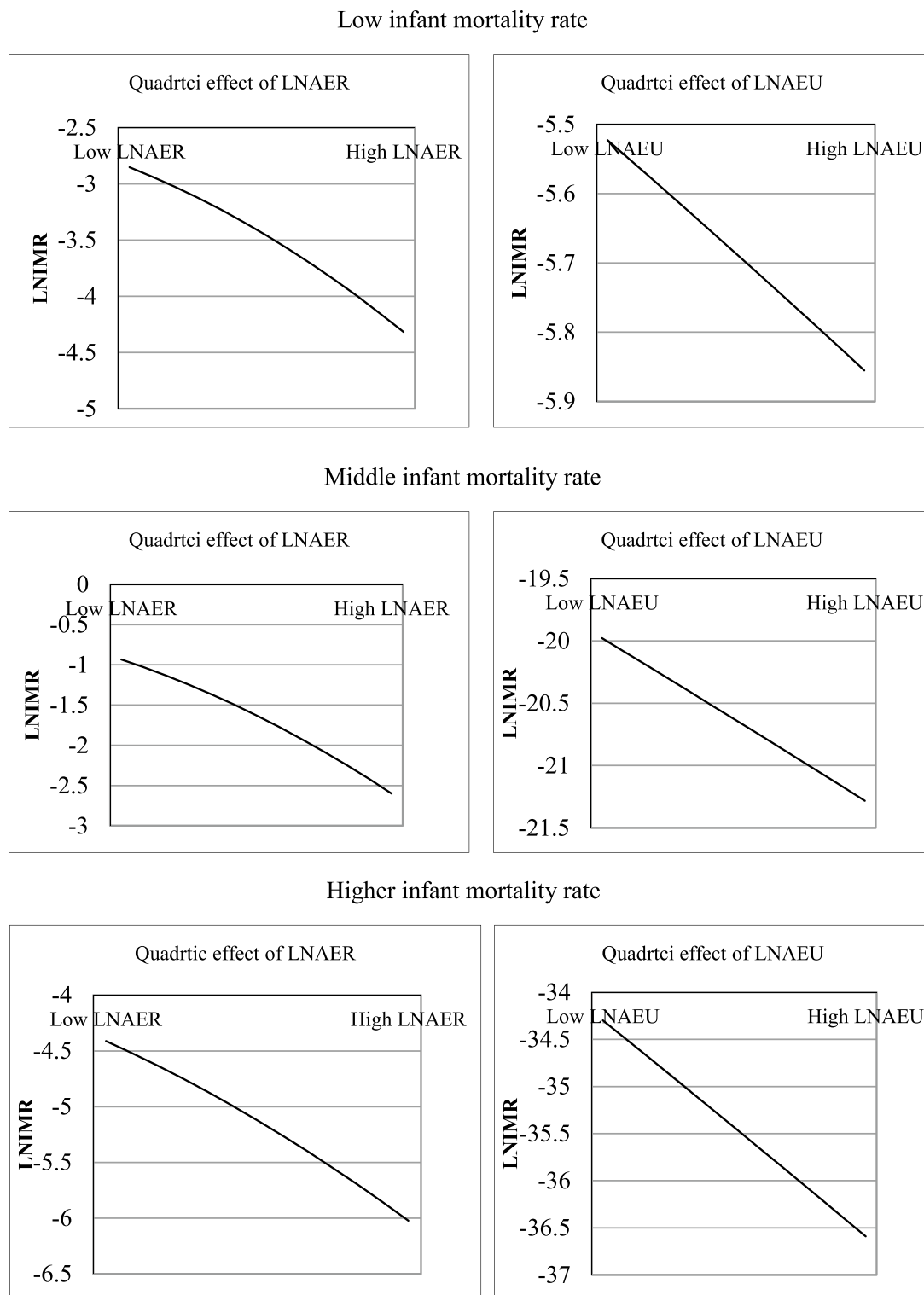


Fig. 4 Quadratic effects of LNAER and LNAEU of developed countries

(2021) investigate the impact of biomass and fossil fuel energy consumption on carbon emissions in Pakistan. The study concludes that the use of biomass and fossil fuel positively increase carbon emissions. Rana et al.

(2021) analyze indoor pollution on women health and infant mortality rate in Myanmar. The study supports the argument that indoor pollution increases infant mortality. Shabbir and Malik (2021) point out that the use

Table 7 Cut-off value of developed countries

	Lower infant mortality	Middle infant mortality	Higher infant mortality	Lower infant mortality	Middle infant mortality
	LNAER			LNAEU	
Level coefficients	2.436	2.584	1.408	2.466	2.023
Squared coefficients	−0.419	−0.456	−0.320	−0.525	−1.227
Cut-off values	2.907	2.833	2.200	2.349	0.824
Antilog of cut-off values	20.363	18.867	9.785	11.414	2.351

of biomass consumption causes respiratory and non-respiratory diseases in women that may cause hypertension, stillbirth, miscarriages, and low birth weight in women. Adeleye et al. (2021) investigate the impact of non-renewable energy consumption on infant mortality rate in 42 Asian and Pacific countries during 2005–2015. The study verifies that non-renewable energy consumption indirectly increases infant mortality through carbon emissions.

Several studies have shown that lack of maternal education is the major cause of high infant mortality rate in developing countries. Sial et al. (2022) identified that school enrollment significantly declined the infant mortality rate. Halinga and Mapoma (2021) explore the link between maternal education and infant mortality rate and point out that improving maternal education may be helpful in reducing the infant mortality rate. Qadir and Majeed (2018) investigated that government expenditure significantly reduced infant mortality rate. Mamoon et al. (2014) explored that higher literacy rate declined infant mortality rate.

The service sector is the jobs of housekeeping, nursing, teaching, and touring. Usually, most of these jobs are performed by women. It is observed that the service sector declines infant mortality rate. Bibi et al. (2020) investigated the women empowerment on infant mortality rate in Pakistan. The study concluded that women empowerment using employment, education level, and decision-making power significantly declined infant mortality rate.

The urbanization is also important determinant of infant mortality rate. Urbanization has two-way impacts on infant mortality rate. The planned urbanization provides better health facilities which decline the infant mortality rate. Qing (2018) identified that urbanization reduces infant mortality rate and crude death rates in global perspective. On the other hand, unplanned urbanization deteriorates the health sector. Dong et al. (2021) pointed that unplanned urbanization increases carbon emissions which badly damage the health sector. The study found that high industrialized and urbanized areas faced more health risks.

Industrialization is an important role in the infant mortality rate. Few studies show that industrialization causes air pollution which increases the infant mortality rate (Tavassoli

et al. 2021; Bauer, et al. 2019). While on the other hand, many studies support the industrialization decline infant mortality rate. In the industries, women are involve in productivity which increases the household income. By increase in the household income, infant mortality declined significantly (Federman and Levine 2005; Beneito and García-Gómez 2019).

After reviewing the pervious literature, it is investigated that access to electricity, biomass energy consumption, industrialization, urbanization, and service sector are the key determinate of the infant mortality rate. There are not so much studies that explored the non-linear analysis of access to electricity and biomass energy consumption on infant mortality. Keeping in view of research gap, the access to electricity is used as the urban and rural access to electricity by using the unique PQR econometric technique at three groups, namely, lower, middle, and higher infant mortality rates of both developed and developing countries. Furthermore, the biomass energy consumption has also non-linear association with infant mortality rate.

Theoretical framework

The present study is the motivation by the Environmental Kuznets Curve (EKC) which proposed the inverted U-shaped Kuznets curve. To explore the access to electricity and biomass energy consumption on infant mortality rate, this study suggests two models. The first model deals with the association between access to electricity and infant mortality rate. Access to electricity is used in terms of rural and urban population access to electricity. Following by Haans et al. (2016) and Sial et al. (2022) suggested that due to large fluctuation in the independent variable behaves a non-linear association with the dependent variable. So, in this study, rural and urban electricity access is behaving a non-linear relationship with the infant mortality rate. It shows that lower rural and urban electricity access increases the infant mortality rate while the higher level of rural and urban electrification declines the infant mortality rate that proposing the inverted U-shaped relationship (Ouedraogo et al. 2021; Ani 2021; Dendup et al. 2018; Lewis 2018; Rutstein 2002).

Table 8 Linearized marginal effect at different quantiles in developing countries

No.	Country	Linear effect of LNAER				Linear effect of LNAEU		
		Mean LNAER	Lower	Middle	Higher	Mean LNAEU	Middle	Higher
1	Algeria	4.59	-0.79	-0.74	-0.64	4.60	-0.07	-0.31
2	Angola	1.30	0.09*	0.05*	-0.04	4.30	-0.03	-0.23
3	Bangladesh	3.06	-0.39	-0.37	-0.36	4.39	-0.04	-0.25
4	Benin	1.92	-0.08	-0.10	-0.15	3.82	0.02	-0.10
5	Bolivia	3.66	-0.55	-0.52	-0.47	4.57	-0.06	-0.30
6	Cambodia	3.08	-0.39	-0.38	-0.36	4.21	-0.02	-0.21
7	Cameroon	2.62	-0.27	-0.27	-0.28	4.39	-0.04	-0.25
8	Congo, Dem	0.64	0.26*	0.21*	0.08*	3.19	0.09*	0.07*
9	Congo, Rep	1.65	-0.01	-0.04	-0.10	3.92	0.01*	-0.13
10	Cote d'Ivoire	3.22	-0.43	-0.41	-0.39	4.37	-0.04	-0.25
11	Egypt	4.57	-0.79	-0.74	-0.63	4.60	-0.07	-0.31
12	El Salvador	4.27	-0.71	-0.66	-0.58	4.57	-0.06	-0.30
13	Eritrea	2.62	-0.27	-0.27	-0.28	4.37	-0.04	-0.25
14	Ethiopia	1.70	-0.02	-0.05	-0.11	4.33	-0.04	-0.24
15	Ghana	2.97	-0.36	-0.35	-0.34	4.40	-0.04	-0.26
16	Honduras	3.93	-0.62	-0.58	-0.52	4.56	-0.06	-0.30
17	India	4.06	-0.65	-0.61	-0.54	4.51	-0.06	-0.29
18	Indonesia	4.25	-0.70	-0.66	-0.58	4.57	-0.06	-0.30
19	Iran	4.56	-0.79	-0.73	-0.63	4.61	-0.07	-0.31
20	Kenya	2.45	-0.22	-0.23	-0.25	4.08	-0.01	-0.17
21	Korea, Dem	3.18	-0.42	-0.40	-0.38	2.95	0.12*	0.13*
22	Kyrgyz R	4.60	-0.80	-0.74	-0.64	4.60	-0.07	-0.31
23	Lebanon	4.59	-0.79	-0.74	-0.64	4.60	-0.07	-0.31
24	Mongolia	3.75	-0.57	-0.54	-0.49	4.58	-0.06	-0.31
25	Morocco	3.94	-0.62	-0.59	-0.52	4.54	-0.06	-0.30
26	Mozambique	0.29	0.36*	0.29*	0.14*	3.79	0.02*	-0.10
27	Myanmar	3.44	-0.49	-0.47	-0.43	4.44	-0.05	-0.27
28	Nepal	3.49	-0.50	-0.48	-0.44	4.43	-0.05	-0.27
29	Nicaragua	3.97	-0.63	-0.59	-0.53	4.56	-0.06	-0.30
30	Niger	1.21	0.11*	0.07*	-0.02	3.76	0.03*	-0.09
31	Nigeria	3.09	-0.39	-0.38	-0.37	4.43	-0.05	-0.27
32	Pakistan	4.07	-0.66	-0.62	-0.54	4.56	-0.06	-0.30
33	Philippines	4.22	-0.70	-0.65	-0.57	4.51	-0.06	-0.29
34	Senegal	2.85	-0.33	-0.32	-0.32	4.32	-0.03	-0.24
35	South Sudan	0.35	0.34*	0.28*	0.13*	2.20	0.20*	0.33*
36	Sri Lanka	4.50	-0.77	-0.72	-0.62	4.59	-0.07	-0.31
37	Sudan	2.84	-0.33	-0.32	-0.32	4.21	-0.02	-0.21
38	Syrian Arab	4.43	-0.75	-0.70	-0.61	4.60	-0.07	-0.31
39	Tanzania	1.33	0.08*	0.04*	-0.05	3.67	0.04*	-0.06
40	Togo	2.09	-0.13	-0.14	-0.18	4.00	0.00*	-0.15
41	Tunisia	4.46	-0.76	-0.71	-0.61	4.60	-0.07	-0.31
42	Ukraine	4.61	-0.80	-0.74	-0.64	4.61	-0.07	-0.31
43	Uzbekistan	4.60	-0.80	-0.74	-0.64	4.61	-0.07	-0.31
44	Vietnam	4.22	-0.70	-0.65	-0.57	4.59	-0.07	-0.31
45	Yemen, Rep	3.69	-0.55	-0.52	-0.47	4.53	-0.06	-0.29
46	Zambia	1.55	0.02*	-0.01	-0.08	3.94	0.01*	-0.14
47	Zimbabwe	2.44	-0.22	-0.22	-0.25	4.45	-0.05	-0.27

* shows higher infant mortality rate countries due to lower access to electricity

Table 9 Linearized marginal effect of developed countries

No.	Country	Linear effect of LNAER				Linear effect of LNAEU		
		Mean LNAER	Lower	Middle	Upper	Mean LNAEU	Lower	Middle
1	Albania	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
2	Argentina	4.50	-1.34	-1.52	-1.47	4.58	-2.34	-9.22
3	Armenia	4.57	-1.39	-1.58	-1.52	4.58	-2.35	-9.22
4	Australia	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
5	Austria	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
6	Azerbaijan	4.60	-1.42	-1.61	-1.54	4.60	-2.36	-9.27
7	Belarus	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
8	Belgium	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
9	Brazil	4.42	-1.27	-1.45	-1.42	4.60	-2.36	-9.26
10	Bulgaria	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
11	Canada	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
12	Chile	4.47	-1.31	-1.49	-1.45	4.60	-2.37	-9.27
13	China	4.57	-1.39	-1.59	-1.52	4.61	-2.37	-9.29
14	Colombia	4.44	-1.28	-1.46	-1.43	4.60	-2.36	-9.26
15	Costa Rica	4.50	-1.34	-1.52	-1.47	4.60	-2.37	-9.27
16	Croatia	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
17	Cuba	4.55	-1.37	-1.56	-1.50	4.61	-2.37	-9.29
18	Cyprus	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
19	Czech Rep	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
20	Denmark	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
21	Dominican Rep	4.39	-1.24	-1.42	-1.40	4.58	-2.35	-9.22
22	Ecuador	4.46	-1.30	-1.48	-1.45	4.59	-2.35	-9.24
23	Estonia	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
24	Finland	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
25	France	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
26	Georgia	4.60	-1.42	-1.61	-1.54	4.61	-2.37	-9.28
27	Germany	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
28	Greece	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
29	Guatemala	3.86	-0.80	-0.94	-1.07	4.52	-2.28	-9.07
30	Hungary	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
31	Iraq	4.54	-1.37	-1.55	-1.50	4.60	-2.37	-9.27
32	Ireland	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
33	Israel	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
34	Italy	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
35	Jamaica	4.40	-1.25	-1.43	-1.41	4.54	-2.30	-9.11
36	Japan	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
37	Jordan	4.57	-1.40	-1.59	-1.52	4.60	-2.37	-9.27
38	Kazakhstan	4.61	-1.43	-1.62	-1.54	4.60	-2.37	-9.28
39	Korea, Rep	4.60	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
40	Latvia	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
41	Lithuania	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
42	Luxembourg	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
43	Malaysia	4.59	-1.41	-1.60	-1.53	4.60	-2.37	-9.27
44	Mauritius	4.59	-1.41	-1.61	-1.53	4.60	-2.37	-9.27
45	Mexico	4.51	-1.35	-1.53	-1.48	4.60	-2.36	-9.26
46	Montenegro	4.61	-1.42	-1.62	-1.54	4.60	-2.37	-9.28
47	Namibia	3.00	-0.08	-0.15	-0.51	4.27	-2.02	-8.45
48	Netherlands	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
49	New Zealand	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28

Table 9 (continued)

No.	Country	Linear effect of LNAER				Linear effect of LNAEU		
		Mean LNAER	Lower	Middle	Upper	Mean LNAEU	Lower	Middle
50	North Macedonia	4.61	-1.42	-1.62	-1.54	4.60	-2.37	-9.28
51	Panama	4.13	-1.02	-1.18	-1.23	4.58	-2.34	-9.22
52	Paraguay	4.31	-1.17	-1.34	-1.35	4.58	-2.35	-9.23
53	Peru	3.38	-0.40	-0.50	-0.76	4.56	-2.32	-9.16
54	Poland	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
55	Portugal	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
56	Romania	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
57	Russian Fed	4.61	-1.42	-1.62	-1.54	4.60	-2.37	-9.27
58	Saudi Arabia	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
59	Serbia	4.61	-1.42	-1.62	-1.54	4.60	-2.37	-9.28
60	Slovak Republic	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
61	Slovenia	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
62	South Africa	4.09	-1.00	-1.15	-1.21	4.46	-2.22	-8.92
63	Spain	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
64	Suriname	4.63	-1.44	-1.64	-1.55	4.61	-2.38	-9.30
65	Sweden	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
66	Switzerland	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
67	Thailand	3.97	-0.89	-1.04	-1.13	4.61	-2.37	-9.29
68	Trinidad and To	4.22	-1.10	-1.26	-1.29	4.61	-2.37	-9.28
69	Turkiye	4.61	-1.42	-1.62	-1.54	4.60	-2.37	-9.28
70	United Arab	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
71	United Kingdom	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
72	United States	4.61	-1.42	-1.62	-1.54	4.61	-2.37	-9.28
73	Uruguay	4.45	-1.30	-1.48	-1.44	4.60	-2.36	-9.26

Furthermore, the populations that do not have an easy and affordable access to clean energy usually consume biomass for cooking, lighting their houses, and for other economic activities. So, the second model explores the relationship between biomass energy consumption and infant mortality rate. Biomass energy consumption is also behaving non-linear relationship with infant mortality rate. The lower biomass consumption declines infant mortality rate while the massive biomass consumption increase infant mortality rate and propose the U-shaped relationship (for details see, Rana et al. 2021; Shabbir and Malik 2021; Gahlawat 2017).

Research methodology

The present study is conducted in the global prospective. In this regard, depending upon data availability, 47 lower- and middle-income countries and 73 higher- and higher-middle-income countries are included in the sample by the classification of the World Development indicators database 2022. Furthermore, this study categorize the lower- and middle-income countries as the developing countries while high-middle-income and higher-income

countries as the developed countries. This study uses annual data for the period 1990–2020. The missing value is forecasted by using *ipolate* command in STATA 16. Furthermore, three quantile groups have built on the basis of infant mortality rate as low infant mortality rate, middle infant mortality rate, and higher mortality rate groups. These groups are based on the natural logarithmic value of infant mortality rate for each year. The details of variables included in both models are presented in Table 1.

This study follows the two models to analyze the access to electricity and biomass consumption on infant mortality rate. In both models, the infant mortality rate is used as the dependent variable. In the literature, many researchers used infant mortality rate as the dependent variable in econometric modeling (Sial et al. 2022; Sule et al. 2022; Shobande 2020). In model 1, the rural and urban electricity access, while in model 2, the biomass energy consumption are used as the key independent variables. The non-linear trend between these variables is confirmed through bi-variate analysis which is not presented here due to conserving time and space. So, the functional form based on the theoretical frame work is discussed as follows:

$$\begin{aligned} \text{LNIMR} = & f(\text{LNAER}, \text{LNAER}^2, \text{LNAEU}, \\ & \text{LNAEU}^2, \text{LNEDU}, \text{LNIND}, \\ & \text{LNSERV}, \text{LNURPOP}) \end{aligned} \tag{1}$$

$$\begin{aligned} \text{LNIMR} = & f(\text{LNCRW}, \text{LNCRW}^2, \\ & \text{LNEDU}, \text{LNIND}, \text{LNSERV}, \\ & \text{LNURPOP}) \end{aligned} \tag{2}$$

On the basis of Eqs. 1 and 2, the models are written as:

$$\begin{aligned} \text{LNIMR}_{it} = & \alpha_1 + \alpha_2 \text{LNAER}_{it} + \alpha_3 \text{LNAER}_{it}^2 \\ & + \alpha_4 \text{LNAEU}_{it} + \alpha_5 \text{LNAEU}_{it}^2 \\ & + \alpha_6 \text{LNEDU}_{it} + \alpha_7 \text{LNSERV}_{it} \\ & + \alpha_8 \text{LNIND}_{it} + \alpha_9 \text{LNURPOP}_{it} + \epsilon \end{aligned} \tag{3}$$

$$\begin{aligned} \text{LNIMR}_{it} = & \beta_1 + \beta_2 \text{LNCRW}_{it} + \beta_3 \text{LNCRW}_{it}^2 \\ & + \beta_4 \text{LNEDU}_{it} + \beta_5 \text{LNSERV}_{it} \\ & + \beta_6 \text{LNIND}_{it} + \beta_7 \text{LNURPOP}_{it} + \epsilon \end{aligned} \tag{4}$$

The quadratic term of rural electricity access (LNAER) and urban electricity access (LNAEU) is used to empirically validation of the inverted U-shaped relationship while the quadratic term of biomass energy consumption (LNCRW) proposes the U-shaped relationship (Haans et al. 2016). To calculate the optimal value of the inverted U-shaped and U-shaped curve, the cut-off value is calculated as follows:

Cut off value of LNAER:

$$\begin{aligned} \frac{\partial \text{LNIMR}_{it}}{\partial \text{LNAER}_{it}} = & \alpha_2 + 2\alpha_3 \text{LNAER}_{it} = 0 \\ \text{LNAER}_{it}^* = & -\frac{\alpha_2}{\alpha_3} \end{aligned} \tag{5}$$

Cut off value of LNAEU:

$$\begin{aligned} \frac{\partial \text{LNIMR}_{it}}{\partial \text{LNAEU}_{it}} = & \alpha_4 + 2\alpha_5 \text{LNAEU}_{it} = 0 \\ \text{LNAEU}_{it}^* = & -\frac{\alpha_4}{\alpha_5} \end{aligned} \tag{6}$$

Cut off value of LNCRW:

$$\begin{aligned} \frac{\partial \text{LNIMR}_{it}}{\partial \text{LNCRW}_{it}} = & \beta_2 + 2\beta_3 \text{LNCRW}_{it} = 0 \\ \text{LNCRW}_{it}^* = & -\frac{\beta_2}{\beta_3} \end{aligned} \tag{7}$$

Equations 5 and 6 demonstrate maximum value of inverted U-shaped function, and Eq. 7 shows the minimum value of U-shaped function of the quadratic functions (Chiang and Wainwright 2005).

The basic diagnostic test shows the presence of outliers and non-normality of the variables, so in this regard, robust Panel Quantile Regression (PQR) is applied for analysis. PQR econometric approach is introduced by Koenker and Bassett (1978) to estimate the model at different quantile groups. Therefore, this study applies three quantile groups based on infant mortality rate which have built as lower infant mortality rate, middle infant mortality rate, and higher infant mortality rate groups at 25%, 50%, and 75% quantiles.

Results and discussion

The descriptive statistics of developed and developing countries are presented in Table 2. Figure 2 shows the plot of pairwise correlations of the dependent and independent variables of both models separately in case of developing and developed countries. In these plots, the dark blue color shows perfect positive correlation, and the dark red color shows perfect negative correlation. This indicates that in both models, independent variables show weak correlation.

The VIF results of both models are presented in Table 3. The observed tolerance values of all explanatory variables are less than 10. The mean values of VIF of both models are 1.70 and 1.76 which are less than 10 indicating the lower multicollinearity and can be used for further econometric analysis.

In the presence of outliers, the robust approach of the Panel Quantile Regression (PQR) estimation technique is used (Sardar and Rehman, 2022). The PQR estimation technique has helped to make static groups; in this regard, three different quantile groups are considered on the basis of infant mortality rate. These quantiles are categorized as low infant mortality rate, middle infant mortality rate, and high infant mortality rate groups. These results of three different groups of developing and developed countries are presented in Tables 4 and 6. For this propose, rural and urban electrification has non-linear association with infant mortality rate; the squares of these two variables can be used in both developing and developed countries. The lack of access to electricity forces the people to depend on biomass. This study uses combustible renewable and waste as proxy of biomass consumption (LNCRW). The LNCRW also behaves non-linearly, so its quadratic term is also used in both developed and developing countries.

Table 4 shows the PQR results of developing countries of both models. In model 1, at all three groups, the level

coefficient of rural electrification (LNAER) positively increases the infant mortality, while the quadratic coefficient significantly declines infant mortality rate. When we trace the level and quadratic coefficients of LNAER using the constant term, mean, and standard deviation, the inverted U-shaped curves are proposed as shown in Fig. 3 (Dawson 2014). Similarly, the coefficient of urban electrification (LNAEU) at the middle and high infant mortality rate group of the level coefficient of LNACEU has positive impact on the LNIMR, while the quadratic coefficient of LNACEU has negative impact on LNIMR (these results are consistent with Ouedraogo et al. 2021; Ani 2021; Dendup et al. 2018; Rutstein 2002). When we trace the level and quadratic coefficient of LNAEU by using the mean, standard deviation and constant term propose the inverted U-shaped relationship. The results of model 2 of developing countries show that less and excessive use of LNCRW both increase infant mortality rate at the middle and higher quantile group (our findings are consistent with Rana et al. 2021; Shabbir and Malik 2021; Gahlawat 2017).

For a clear understanding of the optimal value of the inverted U-shaped curve, the cut-off value is calculated in Table 5. The cut-off value of LNAER and LNAEU of three groups falls between the minimum and maximum values in Table 1.

After detail discussion of the developing countries, Table 6 presents the results of models 1 and 2 of developed countries. These models also follows the PQR technique at three different quantile groups like low, middle, and higher infant mortality rates. In model 1, the level coefficient of rural electrification access (LNAER) positively impacts the infant mortality rate while its quadratic coefficient negatively impacts the infant mortality rate at the three quintile groups. Furthermore, at level the coefficient of urban electrification access (LNAEU) positively impacts the infant mortality rate, while the quadratic coefficient negatively impacts the infant mortality rate at lower and middle quantiles. When we trace the level and quadratic coefficient of rural and urban electrification access by using their mean, standard deviation, and constant term at different quantiles groups, we propose the inverted U-shaped relationship as presented in Fig. 4. In model 2, at lower quintile group, the level coefficient of LNCRW is positive while quadratic coefficient is negative which proposes the inverted U-shaped relationship. While at the middle and higher infant mortality rate groups, both level and quadratic coefficients are positively impacting the infant mortality rate.

Table 7 shows the cut-off values of the rural and urban electrification at different quantile groups. The cut-off value is used to calculate the maximum value of the inverted

U-shaped curve. All cut-off values are between the minimum and maximum values of LNAER and LNAEU as presented in Table 1. It indicates the validation of the inverted U-shaped curve.

In both Tables 4 and 6, there are also some control variables which are also included. The first control variables used in both models show that pre-primary education (LNEDU) has negative impact on the infant mortality rate in all the countries. These results are in line with the findings of Mapoma (2021) and Wang (2021). The pre-primary education enables women to take care of their infants through better medication and provide them proper feeds which help in reducing infant mortality rate. Services sector (LNSERV) has also negative impact on the infant mortality rate in both models. The provision of jobs to women such as housekeeping, nursing, and teaching raises family income which enables them to spend more on the health of their infants. The industrial value added results are opposite in both models. The results of model 1 reveal that industrial value added reduces infant mortality rate. It may be due to an increase in family income and in model 2 expansion of industrial production increases air pollution which raises infant mortality rate (Tavassoli et al. 2021; Bauer et al. 2019).

Following Sial et al. 2022, Rani et al. 2022 and Amjad et al. 2021a, b, c, the level and quadratic coefficients are used to check each country whether it lies at the left or right side of the inverted U-shaped curve by using the linearized marginal effect. Table 8 shows the linearized marginal effect of 47 developing countries at different quantile groups. It is noted from Table 8 that Congo democratic of republican, Korea Democratic, Mozambique, Niger, South Sudan, Tanzania, and Zambia lay before the maturity of the inverted U-shaped curve, while the remaining all developing countries are situated after the maturity side of the inverted U-shaped curve. Table 9 shows the linearized marginal effect of 73 developed countries. It shows that all three groups of all developed countries are situated after the maturity side of the inverted U-shaped curve.

Now, we summarize the access to electricity and biomass energy consumption on infant mortality at different groups in developed and developing countries. It is observed that the developing countries are facing lower access of electricity of their rural and urban population which increases the infant mortality rate. Due to inefficiency of electricity, most of the people use the traditional energy resources and biomass consumption in their houses (dung cake, crop waste, woods, kerosene, and charcoal). These tradition energy sources emit toxic smoke which causes indoor pollution. Usually, women and infants spend most of their time in houses that directly increase the mortality and morbidity. Moreover, with the lack of access to electricity areas, the doctors and nurses hesitate to perform their duties that desperately needed neonatal and maternal attention.

Conclusion and policy recommendations

The present study explores the impact of access to electricity and biomass consumption on infant mortality rate in global perspective from 1990 to 2020. The panel unit root tests show that all the variables included in both models are of mixed order of integration. The study uses NARDL estimation technique to find the long-run and short-run results of the both model. The two separate models have been used to find the impact of access to electricity and biomass consumption on infant mortality rate. In the first model, access to electricity to both rural and urban population has been used as the key independent variable, while in the second model, biomass energy consumption is used as major independent variable. In both models, pre-primary education and industrial value added are used as the control variables. The error correction terms in both models have negative and significant sign which shows that variables are co-integrated. The long-run results of panel NARDL conclude that access to electricity to rural and urban population have inverted U-shaped curve, while biomass energy consumption shows upward sloping curve. The access to electricity in rural and urban population has come up with an important determinant which may be helpful in reducing infant mortality rate. The provision of easy and affordable access to electricity by the government in rural areas may make the women feel comfortable in performing several difficult tasks and get better health care facilities through modern machinery in the health care centers. The marginalized linear effect of each country shows that most of the South Asian and Sub Saharan African countries have relatively less access to electricity and high infant mortality rate.

The study recommends that all the countries of the world should focus on the ways which help in reducing the use of biomass. Furthermore, the provision of affordable and easy access to electricity to common individuals may help in reducing the infant mortality rate. In the backward rural areas where grid electricity is impossible, the government should promote cheaper electrification resources such as energy efficient stoves, solar panels, biogas digesters, and wind turbines for improving the health conditions for women and infants.

Author contribution Nabila Asghar: data curation, visualization, and writing—original draft; Muhammad Asif Amjad: conceptualization, methodology, formal analysis, and software; Hafeez ur Rehman: conceptualization, supervision, investigation, and validation. All authors have contributed in the submitted research paper.

Data availability The data will be made on reasonable request.

Declarations

Ethics approval Not applicable.

Consent for publication The research paper submitted with the mutual consent of authors for publication in Environmental Science and Pollution Research.

Competing interests The authors declare no competing interests.

References

- Adaji EE, Ekezie W, Clifford M, Phalkey R (2019) Understanding the effect of indoor air pollution on pneumonia in children under 5 in low-and middle-income countries: a systematic review of evidence. *Environ Sci Pollut Res* 26(4):3208–3225. <https://doi.org/10.1007/s11356-018-3769-1>
- Adeleye BN, Muhammad AZAM, Osabuohien E, Ogunrinola I, Adekola PO (2021) Infant mortality rates and nonrenewable energy consumption in Asia and the Pacific: the mediating role of carbon emissions
- Amjad MA, Asghar N, Rehman HU (2021b) Can financial development help in raising sustainable economic growth and reduce environmental pollution in Pakistan? Evidence from non linear ARDL model. *Rev Econ Dev Stud* 7(4):475–491. <https://doi.org/10.47067/reads.v7i4>
- Amjad MA, Asghar N, ur Rehman H (2021a) Investigating the role of energy prices in enhancing inflation in Pakistan: fresh insight from asymmetric ARDL model. *Rev Appl Manag Soc Sci* 4(4):811–822. <https://doi.org/10.47067/ramss.v4i4.185>
- Amjad MA, Asghar N, Rehman HU (2021c) Historical aspect of inflation in pre and post Covid-19 pandemic in Pakistan. *Perennial J History* 2(2):383–401. <https://doi.org/10.52700/pjh.v2i2.80>
- Ani VA (2021) Provision of reliable electricity to primary health care facilities in Nigeria—a new focus of interventions. *Intl J Energy Clean Environ* 22(2)
- Arnaut J, Lidman J (2021) Environmental sustainability and economic growth in Greenland: testing the environmental Kuznets curve. *Sustainability* 13(3):1228. <https://doi.org/10.3390/su13031228>
- Bakehe NP (2021) Energy poverty: consequences for respiratory health and labour force participation in Cameroon. *J Environ Econ Pol* 1–13
- Banerjee R, Mishra V, Maruta AA (2021) Energy poverty, health and education outcomes: evidence from the developing world. *Energy Economics* 101:105447
- Bauer SE, Im U, Mezuman K, Gao CY (2019) Desert dust, industrialization, and agricultural fires: health impacts of outdoor air pollution in Africa. *J Geophys Res Atmos* 124(7):4104–4120
- Beneito P, García-Gómez JJ (2019) Gender gaps in wages and mortality rates during industrialization: the case of Alcoy, Spain, 1860–1914 (No. 0119). University of Valencia, ERI-CES
- Benoit K (2011) Linear regression models with logarithmic transformations. *Lond Sch Econ Lond* 22(1):23–36
- Berrod F, Navé L, Verschraegen S (2019) The European Parliament and energy poverty: such a long way to develop a distinctive voice in the Energy Union. In *The European Parliament in Times of EU Crisis* (pp. 365–385). Palgrave Macmillan, Cham
- Bibi M, Khan FA, Irshad I (2020) Women empowerment and infant mortality in Pakistan: micro data evidence. *Pak J Appl Econ* 30(2):181–201
- Buzar S (2016) *Energy poverty in Eastern Europe: hidden geographies of deprivation*. Routledge. <https://doi.org/10.4324/9781315256504>
- Chakraborty D, Mondal NK (2021) Reduction in household air pollution and associated health risk: a pilot study with an improved

- cookstove in rural households. *Clean Technol Environ Policy*, 1–17. <https://doi.org/10.1007/s10098-021-02098-9> <https://doi.org/10.1007/s10098-021-02098-9>
- Chen YJ, Chindarkar N, Xiao Y (2019) Effect of reliable electricity on health facilities, health information, and child and maternal health services utilization: evidence from rural Gujarat, India. *J Health Popul Nutr* 38(1):1–16. <https://doi.org/10.1186/s41043-019-0164-6>
- Chiang AC, Wainwright K (2005) *Fundamental methods of mathematical economics*. McGraw-Hill Irwin. http://thuvienso.vanlanguni.edu.vn/handle/Vanlang_TV/23404
- Coffey ER, Mesenbring EC, Dalaba M, Agao D, Alirigia R, Begay T, ... Hannigan MP (2021) A glimpse into real-world kitchens: Improving our understanding of cookstove usage through in-field photo-observations and improved cooking event detection (CookED) analytics. *Dev Eng*, 6, 100065. <https://doi.org/10.1016/j.deveng.2021.100065>
- Dawson JF (2014) Moderation in management research: what, why, when, and how. *J Bus Psychol* 29(1):1–19. <https://doi.org/10.1007/S10869-013-9308-7>
- Dendup T, Zhao Y, Putra IG (2018) Factors associated with under-five mortality in Bhutan: an analysis of the Bhutan National Health Survey 2012. *BMC Public Health*, 18(1375). <https://doi.org/10.1186/s12889-018-6308-6>
- Dherani M, Pope D et al (2008) Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. *Bull World Health Organ* 86(5):390–398C
- Dong H, Xue M, Xiao Y, Liu Y (2021) Do carbon emissions impact the health of residents? Considering China's industrialization and urbanization. *Sci Total Environ* 758:143688. <https://doi.org/10.1016/j.scitotenv.2020.143688>
- Enyew HD, Mereta ST, Hailu AB (2021) Biomass fuel use and acute respiratory infection among children younger than 5 years in Ethiopia: a systematic review and meta-analysis. *Public Health* 193:29–40. <https://doi.org/10.1016/j.puhe.2020.12.016>
- Fahmy E, Gordon D, Patsios D (2011) Predicting fuel poverty at a small-area level in England. *Energy Policy* 39(7):4370–4377. <https://doi.org/10.1016/j.enpol.2011.04.057>
- Falk J, Angelmahr M, Schade W, Schenk-Mathes H (2021) Socio-economic impacts and challenges associated with the electrification of a remote area in rural Tanzania through a mini-grid system. *Energy Ecol Environ*, 1–18. <https://doi.org/10.1007/s40974-021-00216-3>
- Federman M, Levine DI (2005) Industrialization and infant mortality
- Fujii T, Shonchoy AS, Xu S (2018) Impact of electrification on children's nutritional status in rural Bangladesh. *World Development* 102:315–330
- Gahlawat IN (2017) A feasibility and viability analysis of biomass combustion products with implied impact on health as well as environment. *Integr J Soc Sci* 4(1):26–31
- Haans RF, Pieters C, He ZL (2016) Thinking about U: theorizing and testing U-and inverted U-shaped relationships in strategy research. *Strateg Manag J* 37(7):1177–1195. <https://doi.org/10.1002/smj.2399>
- Halinga J, Mapoma C (2021) Infant mortality decline in Zambia: to what extent did maternal education influence infant mortality rate decline for the period 1992 to 2018?. <https://doi.org/10.21203/rs.3.rs-493349/v1>
- Han C, Xu R, Zhang Y, Yu W, Zhang Z, Morawska L, ... Guo Y (2021) Air pollution control efficacy and health impacts: a global observational study from 2000 to 2016. *Environ Pollut*, 287, 117211. <https://doi.org/10.1016/j.envpol.2021.117211> <https://doi.org/10.1016/j.envpol.2021.117211>
- Hanif N, Arshed N, Aziz O (2019) On interaction of the energy: human capital Kuznets curve?. *Environ Dev Sustain*. <https://doi.org/10.1007/s10668-019-00536-9> <https://doi.org/10.1007/s10668-019-00536-9>
- IEA: <http://www.iea.org/topics/energy-poverty/>
- IEA (2017) *World energy outlook 2017*. <https://www.iea.org/reports/world-energy-outlook-2017>
- IEA (2019) *World energy outlook 2019*. <https://www.iea.org/reports/world-energy-outlook-2019>
- Jalil SA, Yazan FNN (2018) An investigation on environmental Kuznet's curve hypothesis in upper middle-income countries: does an inverted U-shaped exist for CO2 emissions? *Adv Transport Logis Res* 1:462–474
- James BS, Shetty RS, Kamath A, Shetty A (2020) Household cooking fuel use and its health effects among rural women in southern India—a cross-sectional study. *PloS one* 15(4):e0231757. <https://doi.org/10.1371/journal.pone.0231757>
- Javadi D, Ssempebwa J, Isunju JB, Yevo L, Amu A, Nabiwemba E, ... Severi L (2020) Implementation research on sustainable electrification of rural primary care facilities in Ghana and Uganda. *Health Policy Plan* 35(Supplement_2):ii124–ii136
- Kuznets S (1955) Economic growth and income inequality. *Am Econ Rev* 45(1):1–28
- Lewis J (2018) Infant health, women's fertility, and rural electrification in the United States, 1930–1960. *J Econ Hist* 78(1):118–154. <https://doi.org/10.1017/S0022050718000050>
- Maher BA, O'Sullivan V, Feeney J, Gonet T, Kenny RA (2021) Indoor particulate air pollution from open fires and the cognitive function of older people. *Environ Res* 192:110298. <https://doi.org/10.1016/j.envres.2020.110298>
- Mamoon D, Raza S, Arshed N (2014) Impact of health capital and education on infant mortality rate of Districts of Punjab. *J Manag Res* 1(2):1–9
- Mari-Dell'Olmo M, Novoa AM, Camprubí L, Peralta A, Vázquez-Vera H, Bosch J, Borrell C (2017) Housing policies and health inequalities. *Intl J Health Serv*, 47(2):207–232. <https://doi.org/10.1177/2F0020731416684292>
- Mohammed M, Akuoko M (2022) Subnational variations in electricity access and infant mortality: evidence from Ghana. *Health Policy OPEN* 3:100057. <https://doi.org/10.1016/j.hpopen.2021.100057>
- Moner-Girona M, Kakoulaki G, Falchetta G, Weiss DJ, Taylor N (2021) Achieving universal electrification of rural healthcare facilities in sub-Saharan Africa with decentralized renewable energy technologies. *Joule* 5(10):2687–2714. <https://doi.org/10.1016/j.joule.2021.09.010>
- Nano E (2021) Electrifying Nigeria: the household-level impact of access to electricity on consumption, education and employment. In *Energy, COVID, and Climate Change*, 1st IAEE Online Conference, June 7–9, 2021. International Association for Energy Economics
- Nawaz S (2021) Energy poverty, climate shocks, and health deprivations. *Energy Economics*, 105338
- Nesterovic A, Djatkov D, Viskovic M, Martinov M, Adamovic D (2021) Air pollutants emissions from biomass combustion in the City of Novi Sad, Serbia. *Biomass Convers Biorefinery* 1–12. <https://doi.org/10.1007/s13399-021-01882-3> <https://doi.org/10.1007/s13399-021-01882-3>
- Nikus TA, Wayessa BG (2021) Determinants of household energy choice in West Shoa Zone: in the case of Ambo Town. *Intl J Green Energy* 1–12. <https://doi.org/10.1080/15435075.2021.1941038> <https://doi.org/10.1080/15435075.2021.1941038>
- Odo DB, Yang IA, Knibbs LD (2021) A systematic review and appraisal of epidemiological studies on household fuel use and its health effects using demographic and health surveys. *Int J*

- Environ Res Public Health 18(4):1411. <https://doi.org/10.3390/ijerph18041411>
- Oliveras L, Peralta A, Palència L, Gotsens M, López MJ, Artazcoz L, ... Marí-Dell'Olmo M (2021) Energy poverty and health: trends in the European Union before and during the economic crisis, 2007–2016. *Health & Place*, 67, 102294 <https://doi.org/10.1016/j.healthplace.2020.102294>
- Ouedraogo I, Jiya AN, Diandac I (2021) Access to electricity and health capital accumulation in Sub-Saharan Africa
- Pope DP, Mishra V, Thompson L, Siddiqui AR, Rehfuess EA, Weber M, Bruce NG (2010) Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. *Epidemiol Rev* 32(1):70–81. <https://doi.org/10.1093/epirev/mxq005>
- Qadir N, Majeed MT (2018) The impact of trade liberalization on health: evidence from Pakistan. *Empirical Econ Rev* 1(1):71–108
- Qing W (2018) Urbanization and global health: the role of air pollution. *Iran J Public Health* 47(11):1644
- Rana J, Islam RM, Khan MN, Aliani R, Oulhote Y (2021) Association between household air pollution and child mortality in Myanmar using a multilevel mixed-effects Poisson regression with robust variance. *Sci Rep* 11(1):1–10. <https://doi.org/10.1038/s41598-021-92193-0>
- Rani T, Amjad MA, Asghar N, Rehman HU (2022) Revisiting the environmental impact of financial development on economic growth and carbon emissions: evidence from South Asian economies. *Clean Technol Environ Policy*, 19. <https://doi.org/10.1007/s10098-022-02360-8>
- Rutstein SO (2002) Factors associated with trends in infant and child mortality in developing countries during the 1990s. *Bull W Health Organ* 78(10):1256–1270
- Shabbir SW, Malik N (2021) Agriculture biomass and indoor air pollution as risk factors for women health. *Rev Educ Adm LAW* 4(2):299–310. <https://doi.org/10.47067/real.v4i2.141>
- Shaikh GM, Riaz S, Ahmad R (2020) Does economic expansion costs environmental degradation? Testing Kuznet's inverse u shaped curve in Pakistan country. *PalArch's J Archaeol Egypt/egyptol* 17(3):916–938
- Shobande OA (2020) The effects of energy use on infant mortality rates in Africa. *Environ Sustain Indicators* 5:100015. <https://doi.org/10.1016/j.indic.2019.100015>
- Siah AK, Lee GH (2015) Female labour force participation, infant mortality and fertility in Malaysia. *J Asia Pacific Econ* 20(4):613–629. <https://doi.org/10.1080/13547860.2015.1045326>
- Sial MH, Arshed N, Amjad MA, Khan YA (2022) Nexus between fossil fuel consumption and infant mortality rate: a non-linear analysis. *Environ Sci Pollut Res* 1–10. <https://doi.org/10.1007/s11356-022-19975-5>
- Sule IK, Yusuf AM, Salihu M-K (2022) Impact of energy poverty on education inequality and infant mortality in some selected African countries. *Energy Nexus* 5:100034. <https://doi.org/10.1016/J.NEXUS.2021.100034>
- Tavassoli N, Noghani-behambari H, Noghani F, Toranji M (2021) Upswing in industrial activity and infant mortality during late 19th century US. *arXiv preprint arXiv:2101.02590*. doi: <https://doi.org/10.20448/journal.505.2020.61.1.13>
- Teng JZ, Khan MK, Khan MI, Chishti MZ, Khan MO (2021) Effect of foreign direct investment on CO₂ emission with the role of globalization, institutional quality with pooled mean group panel ARDL. *Environ Sci Pollut Res* 28(5):5271–5282. <https://doi.org/10.1007/s11356-020-10823-y>
- Tripathi DS (2021) Relationship between urbanization and health outcomes in Indian states relationship between urbanization and health outcomes in Indian states
- UNDP (United Nations Development Program) (2016) Human development report. Human Development for Everyone
- UNEP (United Nations Environment Programme) (2016). UNEP frontiers 2016 report; emerging issues of environmental concern
- UNFCCC (United Nations Framework Convention on Climate Change) (2015) The Paris Agreement
- Wang H, Asif Amjad M, Arshed N, Mohamed A, Ali S, Haider Jafri MA, Khan YA (2022) Fossil energy demand and economic Development in BRICS countries. *Front Energy Res* 10:842793. <https://doi.org/10.3389/fenrg.2022.842793>
- Wang T (2021) The effect of female education on child mortality: evidence from Indonesia. *Appl Econ* 53(27):3207–3222. <https://doi.org/10.1080/00036846.2021.1877253>
- Wang (2018) Urbanization and global health: the role of air pollution. In *Iran J Public Health* (Vol. 47, Issue 11). <http://ijph.tums.ac.ir>
- WHO (World Health Organization) (2011) Health impacts of indoor air pollution, 2011. Retrieved from: http://www.who.int/indoorair/health_impacts/en/
- World Health Organization (2020) Global progress report on water, sanitation and hygiene in health care facilities: fundamentals first. UNICEF
- World Health Organization (n.d.) Air pollution, percentage of population using biomass fuels, Millennium Indicators Database, United Nations, Department of Economic and Social Affairs, Economic and Social Development, Statistics Division. http://millenniumindicators.un.org/unsd/mi/mi_series_results.asp?rowId=712
- Yousaf H, Amin A, Baloch A, Akbar M (2021) Investigating household sector's non-renewables, biomass energy consumption and carbon emissions for Pakistan. *Environ Sci Pollut Res*, 1–11 <https://doi.org/10.1007/s11356-021-12990-y>
- Zahid T, Arshed N, Munir M, Hameed K (2020) Role of energy consumption preferences on human development: a study of SAARC region. *Econ Chang Restruct* 54(1):121–144. <https://doi.org/10.1007/s10644-020-09279-4>
- Zubi G, Fracastoro GV, Lujano-Rojas JM, El Bakari K, Andrews D (2019) The unlocked potential of solar home systems; an effective way to overcome domestic energy poverty in developing regions. *Renewable Energy* 132:1425–1435. <https://doi.org/10.1016/j.renene.2018.08.093>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.