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Multidimensional energy poverty and acute respiratory infection in children under 5 years of age: evidence from 22 low-income and middle-income countries

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ABSTRACT

Background In low-income and middle-income countries (LMICs), energy poverty has predominantly been studied from the unidimensional perspective of indoor air pollution. Acute respiratory infection (ARI) in children under 5 years of age is the most important disease associated with indoor air pollution attributable to solid fuel use in LMICs. This study aimed to extend the existing knowledge on the association between energy poverty and ARI among children under 5 years of age in LMICs, by adopting a multidimensional perspective.

Methods Using Demographic and Health Surveys from 22 LMICs, data from 483 088 children were analysed (mean age 2.00 years (SD 1.41); 51.3% male). Energy poverty was measured using the Multidimensional Energy Poverty Index (MEPI) (range 0–1), which comprises five dimensions of essential energy services. Binary logistic regression models were conducted to study the association between MEPI and ARI, adjusting for child, maternal, household and environmental characteristics.

Results A 0.1 increase in MEPI score was associated with greater odds of ARI (aOR 1.05; 95% CI 1.04 to 1.07). Likewise, MEPI indicators using biomass for cooking (aOR 1.15; 95% CI 1.07 to 1.23) and lack of access to electricity (aOR 1.17; 95% CI 1.10 to 1.26), entertainment/education appliances (aOR 1.07; 95% CI 1.02 to 1.13) and household appliances (aOR 1.12; 95% CI 1.04 to 1.21) were associated with greater odds of ARI.

Conclusion Multidimensional energy poverty was associated with greater odds of ARI in children under 5 years of age living in 22 LMICs. Hence, our findings justify the design and implementation of interventions that address energy poverty from a multidimensional perspective, integrating energy affordability and accessibility.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Regardless of growing interest and awareness of the impact of energy poverty on children's respiratory health, studies on this association in low-income and middle-income countries (LMICs) have mainly relied on unidimensional measures of energy poverty, with a focus on indoor air pollution. This study extends the existing knowledge by adopting a multidimensional perspective on energy poverty, which integrates aspects of energy accessibility and affordability, and its association with acute respiratory infection.

WHAT THIS STUDY ADDS

⇒ This study demonstrates that multidimensional energy poverty is associated with acute respiratory infection in children under 5 years of age in LMICs.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The findings encourage the design of interventions that improve both energy affordability and accessibility. Besides the implementation of clean cooking practices, access to electricity and ownership of household, education and entertainment appliances could equally contribute to the mitigation of energy poverty and its effects on children's respiratory health in LMICs.

BACKGROUND

Energy poverty has been associated with a diverse range of adverse health impacts, including respiratory disease in children.[1 2] A recent definition that aims to overcome geographical barriers, considers energy poverty as the inability of a household to secure a socially and materially required level of energy services in the home.[2] Globally, a consensus has been reached that reducing energy poverty is fundamental to socioeconomic development and health.[3]

Both accessibility and affordability are relevant to the concept of energy poverty. In high-income nations, energy poverty is primarily addressed from an affordability perspective, based on household energy expenditures. In low-income and middle-income countries (LMICs), energy poverty is mainly considered as a lack of accessibility to modern forms of energy, such as clean cooking fuels.[4 5] Indoor air pollution in LMICs is largely caused by solid fuel combustion for heating and cooking.[6] Worldwide, around 2.4 billion people use solid fuels for cooking, most of them residing in LMICs.[7] The majority of studies in LMICs address energy poverty from the unidimensional perspective of indoor air pollution.[8] A more comprehensive way to capture energy poverty is essential for studies in LMICs since households might have access to modern energy services, yet they are unable to afford adequate levels of energy services.

Acute respiratory infection (ARI) is an infection of the upper or lower respiratory tract, characterised by symptoms such as cough and shortness of breath.[9] ARI in children under 5 years of age is the most important disease associated with indoor air pollution attributable to solid fuel use, with the highest burden occurring in LMICs.[10–12] In fact, almost half of all deaths due to ARI among children under 5 years of age is caused by indoor air pollution.[6] ARI is also associated with family socioeconomic status, an important predictor of energy affordability.[13 14] A multidimensional measurement of energy poverty comprehends a more accurate picture of the extent and severity of the inequality in ARI experienced by children in LMICs.

The Multidimensional Energy Poverty Index (MEPI), established by Nussbaumer *et al*[5] offers a wider framework to study the effects of energy poverty on ARI in children. It uses a multidimensional approach to capture a household's deprivation in modern energy access, linked with the intensity and incidence of energy poverty. It, therefore, integrates aspects of both energy accessibility and affordability, by complementing commonly used indicators of electricity access and cooking fuel use with telecommunication means and household appliance ownership.[5]

This study aims to extend the existing knowledge on the impact of energy poverty on ARI among children under 5 years of age in LMICs, by adopting a multidimensional perspective on energy poverty. Data from children under 5 years of age who responded to the Demographic and Health Survey (DHS) within the past 10 years are used to assess the association between multidimensional energy poverty and ARI.[15] In addition, the association of the individual MEPI indicators with ARI is assessed.

METHODS

This study followed the Strenghtening the reporting of observational studies in epidemiology (STROBE) cross-sectional reporting guidelines (online supplemental material 1).[16]

Study design

A community-based cross-sectional study was conducted across 22 LMICs. Data from the most recently available population-based DHS within the past 10 years (2012–2022) were used.[15] DHS collects data from nationally representative, randomly selected samples of women of reproductive age (15–49) and their children (0–5 years) using the household and woman's questionnaires. Each country follows a two-stage stratified cluster sampling technique, with probability proportional to the cluster size. Households are then randomly selected in each cluster. The surveys have large sample sizes (5000–30 000 households) and are conducted every 5 years. Standardised questionnaires are used with fieldwork supported by the United States Agency for International Development. Each survey round consists of a household questionnaire used to collect information on characteristics of the household's dwelling unit and of usual residents and visitors. It is also used to identify eligible members of the household for the woman's questionnaire. Data from the household and woman's questionnaires were merged using Integrated Public Use Microdata Series DHS to obtain a working dataset for this study.[17]

Study population

The first selection of DHS surveys was made based on (1) DHS survey data available from within the previous 10 years (2012–2022), (2) children living in LMIC according to the World Bank classification,[18] (3) the presence of MEPI indicators [5], (4) presence of the variables cough and shortness of breath, used to compose the outcome variable ARI according to the definition adopted by the UNICEF Multiple Indicator Cluster Surveys[19] and (5) presence of relevant explanatory variables. The first selection included 410 567 households with 633 542 children from 31 LMICs.

To obtain the final sample, visitors (n=20 953), countries (n=9) and children (n=33 773) with missing (in)dependent variables were excluded. The final sample included 483 088 children from 22 countries, living in 314 002 different households (online supplemental material 2).

Acute respiratory infection

The outcome of interest is the presence of ARI among all children under 5 years of age. ARI (yes/no) is defined as a cough accompanied by short, rapid breathing, according to the UNICEF Multiple Indicator Cluster Surveys, in the 2 weeks preceding the survey.[19] Presence of cough and shortness of breath were therefore combined to compose the outcome variable ARI. The measure for ARI was modelled as a binary outcome (yes/no).

To identify the presence of a cough, mothers were asked the following question: 'Has (name) had an illness with a cough at any time in the last 2 weeks?' Answer options were 'yes', 'no' and 'don't know'. Participants who answered 'don't know' were excluded from the analysis.

From 2012 to 2014, mothers of children who had a cough in the past 2 weeks were asked 'when (name) had an illness with a cough, did he/she breathe faster than usual with short, rapid breaths or have difficulty breathing?'. From 2015 onwards all mothers of children, regardless of whether they experienced a cough in the last 2 weeks, were asked 'has (name) had fast, short, rapid breaths or difficulty breathing at any time in the last 2 weeks?'. Answer options in both cases were 'yes', 'no' and 'don't know'.

Cases that did not report the presence of a cough in the past 2 weeks with or without shortness of breath were categorised as not having ARI. Cases that had a cough but answered 'don't know' to the shortness of breath question were excluded from the analysis.

Multidimensional energy poverty

MEPI was adopted to measure multidimensional energy poverty, which consists of five dimensions of essential energy services and includes six indicators: using biomass for cooking, indoor pollution, electricity access, household appliance ownership, entertainment/education appliance ownership and telecommunication means (table 1). Whereas the indicator 'using biomass for cooking' determines the release of polluting substances while cooking, indoor pollution further specifies the level of exposure to polluting substances inside the dwelling, which strongly increases when cooking inside in the absence of a separate kitchen.[5] A modified MEPI was used due to missing values in the indicator 'household has a separate room used as kitchen' (48.1%) and the indicator 'household has a television' (46.3%). Cases with relevant data for at least one of the two variables were included in the analyses (table 1). Indoor pollution was determined by the single variable 'where cooking is usually done (inside/outside)' when 'household has a separate room used as

Table 1 Dimension, indicator and weighting of the Multidimensional Energy Poverty Index (MEPI)

Dimension	Indicator (weighting)	Variable	Deprivation threshold
Cooking	Using biomass for cooking (0.2)	Type of cooking fuel	Use any fuel beside electricity, LPG, kerosene, natural gas or biogas
	Indoor pollution (0.2)	Household has separate room used as kitchen	Household has no separate room used as kitchen and cooks in the house, if using any fuel beside electricity, LPG, natural gas or biogas*
		Where cooking is usually done	
Lighting	Electricity access (0.2)	Household has access to electricity	Household has no access to electricity
Household appliances	Household appliance ownership (0.13)	Household has a fridge	Household has no fridge
Entertainment/education	Entertainment/education appliance ownership (0.13)	Household has a radio	Household has no radio or television
		Household has a television	
Communication	Telecommunication means (0.13)	Household has a mobile phone	Household has no mobile phone or land line phone
		Household has a land line phone	

Source: Nussbaumer *et al*.[5]
*Replacing the indicator 'Food cooked on stove or open fire (no hood/chimney)' of the original MEPI by 'indoor, if using any fuel beside electricity, LPG, natural gas or biogas'.[40 41]
LPG, liquefied petroleum gas.

kitchen' was missing. Entertainment/education was determined by the single variable 'household has a radio (yes/no)' when 'household has a television' was missing.

A household was classified as energy poor if the sum of assigned weights to each dimension exceeds a 0.30 cut-off value as defined by Nussbaumer *et al*[5]

Covariates

Covariates were selected based on previous literature and availability in the DHS dataset.[20 21] Child's characteristics included age, sex (male, female), birth order (first-born, not first-born), breastfeeding status (ever breastfed/still breastfeeding, never), vitamin A supplementation in the last 6 months (yes, no), BCG vaccination (yes, no), low birth weight (yes, no) and treatment sought for fever/cough (yes, no). Maternal characteristics included age and education level (no education, primary, secondary, higher). Household characteristics included household smoking (never, daily, more than daily), source of drinking water (improved, unimproved), shelter index (low (0–1), intermediate (2–4), high (5–6)) and crowding (yes, no). Following previous work, the shelter index represents the sum of floor, wall and roof material, where natural material was coded as 0, rudimentary as 1 and finished as 2.[22] Crowding was defined as more than 3 persons per room used for sleeping, a modified definition by UN Habitat.[23]

Environmental characteristics included urban–rural status (urban, rural) and rainy season at the time of the interview (yes, no). The variable rainy season was included as a contextual factor to indicate whether the interview took place during the rainy or dry season, with information obtained from the World Bank Climate Change Knowledge Portal.[24] Country of residence was considered as a covariate to compensate for differences across countries.

Statistical analysis

Descriptive statistics were used to characterise the sample, and summarised by the number of cases (n) and percentages (%) for categorical variables and mean and SD for continuous variables. The association between ARI as the main outcome variable and MEPI/energy poverty status as the main determinant was assessed using binary logistic regression. A unit of change of 0.1 for MEPI was used in the regression model. The regression model was adjusted for child's age, child's sex, first-born, vitamin A supplementation, BCG vaccination, treatment sought for fever/cough, low birth weight, breastfeeding status, maternal age, maternal education, shelter index, drinking water source, household smoking, crowding, urban–rural status, rainy season and country. Model fit was examined using Nagelkerke's R^2. Tests for multicollinearity were performed using variance inflation factors.

The interaction effect between MEPI and child's age, child's sex, low birth weight, first-born, shelter index, household smoking, crowding, urban–rural status, rain season and country was evaluated by adding interaction terms to the adjusted models.[10 14 25–28] The two-sided significance threshold, after Bonferroni correction for multiple testing, was set at 0.05 (original p value)/10 (number of interaction tests performed)=p=0.005. Stratified logistic regression analyses were run for the variables with statistically significant interaction terms. Bonferroni correction was applied for multiple testing per subgroup (0.05 (original p value)/8 (number of subgroups)=p=0.006).

Eight of the 17 covariates had missing values for ≥2% of the sample: child's age (5.5%), vitamin A supplementation (7.1%), breastfeeding status (13.4%), BCG vaccination (16.4%), treatment sought for fever/cough (77.7%), low birth weight (41.0%), shelter index (4.4%) and household smoking (2.1%). Multiple imputation (n=10 imputations) was used to impute the missing data using the chained equations method in R V.4.2.0.[29] Rubin rules were used to obtain pooled estimates of ORs and their 95% CIs. Statistical significance in the adjusted model was set at $p<0.05$.

All statistical analyses were performed using IBM SPSS Statistics for Windows, V.28.[30] The regression analyses accounted for weighting, clustering and stratification using the Complex Samples Package in SPSS. Sampling weights were applied to the regression model to adjust for disproportionate sampling and non-response. The analyses considered the hierarchical structure of the sample. The clustering effect was accounted for by using the unique sample-case primary sampling unit identifier variable. The stratified sampling design was accounted for by using the unique cross-sample sampling strata variable.[17]

RESULTS

Population characteristics

The mean age of children was 2.00 years (SD 1.41); 51.3% were male; 25.7% resided in urban areas and 54.6% of the children lived in the South Asia region at the time of the survey, followed by 19.4% in Eastern Africa and 16.9% in Western Africa. In total, 38.1% of mothers had no education and 23.8% had a primary education level (online supplemental table 1). The mean MEPI

Table 2 Energy poverty according to MEPI

MEPI indicators	
Using biomass for cooking, n (%) yes	388 803 (80.5)*
Indoor air pollution, n (%) yes	126 909 (26.3)
Electricity access, n (%) yes	280 013 (58.0)
Household appliance ownership, n (%) has a fridge	80 146 (16.6)
Entertainment/education, n (%) yes	166 196 (34.4)
Telecommunication means, n (%) yes	401 097 (83.0)
Energy poverty according to MEPI	
MEPI, mean (SD)†	0.51 (0.23)
Energy poverty, n (%)‡ yes	401 833 (83.2)

Table is based on non-imputed dataset.
*Percentages are based on unweighted sample.
†MEPI represents the sum of weights for each indicator.
‡Energy poverty status was defined with an MEPI cut-off value of 0.30.
MEPI, Multidimensional Energy Poverty Index.

was 0.51 (SD 0.23); 83.2% of children were considered to live in energy poverty conditions (table 2). In the overall sample, 7.8% of children suffered from ARI during the 2 weeks preceding the survey (online supplemental table 1).

All variance inflation factors were lower than 4, suggesting low multicollinearity. No violation of basic assumptions for regression was found.

Association between MEPI and ARI

The adjusted model indicated that every 0.1 increase in MEPI was associated with greater odds of ARI in children under 5 years of age (aOR 1.05; 95% CI 1.04 to 1.07; R^2 0.08) (table 3). Similarly, living in energy poverty was positively associated with ARI (aOR 1.18; 95% CI 1.09 to 1.27; R^2 0.08).

In addition, the association between the individual MEPI indicators and ARI was studied (table 3). The adjusted model demonstrated a positive association between using biomass for cooking and ARI (aOR 1.15; 95% CI 1.07 to 1.23; R^2 0.08), between lack of access to electricity and ARI (aOR 1.17; 95% CI 1.10 to 1.26; R^2 0.08), between lack of entertainment/education appliances and ARI (aOR 1.07; 95% CI 1.02 to 1.13; R^2 0.08) and between lack of household appliance ownership and ARI (aOR 1.12; 95% CI 1.04 to 1.21; R^2 0.08).

Interaction analyses

A significant interaction term was found for ARI between MEPI and child's age (p<0.001) and MEPI and country (p<0.001). Stratified analyses (table 4) indicated a significant aOR for the association between MEPI and ARI among children aged 0–2 years (aOR 1.07; 95% CI 1.05 to 1.09) and 2–5 years (aOR 1.04; 95% CI 1.03 to 1.06). Stratified analyses for region showed a significant association between MEPI and ARI in South Asia (aOR 1.05; 95% CI 1.03 to 1.07), Eastern Africa (aOR 1.07;

Table 3 Associations between MEPI and ARI

Multidimensional energy poverty	ARI, N (%)	ARI aOR (95% CI)*	P value§	R^2
Energy poverty†				
No	4931 (6.09)	Ref	Ref	
Yes	32 910 (8.19)	1.18 (1.09 to 1.27)	**<0.001**	0.08
MEPI‡	37 841 (7.8)	1.05 (1.04 to 1.07)	**<0.001**	0.08
MEPI indicators	**ARI, N (%)**	**ARI aOR (95% CI)***	**P value§**	
Using biomass for cooking				
No	5734 (6.08)	Ref	Ref	
Yes	32 107 (8.26)	1.15 (1.07 to 1.23)	**<0.001**	0.08
Indoor pollution				
No	28 510 (8.00)	Ref	Ref	
Yes	9331 (7.35)	0.98 (0.92 to 1.03)	0.38	0.05
Electricity access				
No	19 922 (9.81)	1.17 (1.10 to 1.26)	**<0.001**	0.08
Yes	17 919 (6.40)	Ref	Ref	
Household appliance ownership				
No	32 948 (8.18)	1.12 (1.04 to 1.21)	**0.002**	0.08
Yes	4893 (6.11)	Ref	Ref	
Entertainment/education appliance ownership				
No	22 752 (7.18)	1.07 (1.02 to 1.13)	**0.01**	0.08
Yes	15 089 (9.08)	Ref	Ref	
Telecommunication means				
No	8047 (9.81)	1.05 (0.98 to 1.11)	0.17	0.08
Yes	29 794 (7.43)	Ref	Ref	

Table is based on an imputed dataset.
P values are based on binary logistic regression models.
*Model adjusted for: child's age, child's sex, first-born, vitamin A supplementation, breastfeeding status, BCG vaccination, treatment sought for fever/cough, low birth weight, maternal age, maternal education, shelter index, drinking water source, household smoking, crowding, urban–rural status, rainy season and country.
†Energy poverty status was defined with an MEPI cut-off value of 0.30.
‡Unit of change=0.1.
§P-values in bold are significant.
aOR, adjusted OR; ARI, acute respiratory infection; MEPI, Multidimensional Energy Poverty Index; n, total number of cases.

Table 4 Associations between MEPI and ARI by child age and region

Subgroup	ARI, N (%) yes	ARI aOR (95% CI)*	P value**
MEPI per child's age†‡			
0–2 years (N=172 665 (44.5%))	15 873 (9.2)	1.07 (1.05 to 1.09)	**<0.001**
2–5 years (N=215 386 (55.5%))	16 040 (7.4)	1.04 (1.03 to 1.06)	**<0.001**
MEPI per region‡§,¶			
South Asia (N=191 949 (49.4%))	16 817 (6.38)	1.05 (1.03 to 1.07)	**<0.001**
Southeast Asia (N=3840 (1.0%))	363 (8.17)	1.04 (0.94 to 1.14)	0.47
Western Africa (N=74 315 (19.2%))	4991 (6.12)	1.02 (0.99 to 1.05)	0.18
Eastern Africa (N=81 056 (20.9%))	10 995 (11.76)	1.07 (1.05 to 1.09)	**<0.001**
Central Africa (N=30 459 (7.8%))	3845 (11.63)	1.10 (1.04 to 1.16)	**0.001**
Southern Africa (N=6432 (1.7%))	830 (11.97)	1.02 (0.98 to 1.07)	0.37

Table is based on an imputed dataset.
P values are based on binary logistic regression models.
*Model adjusted for: child's age, child's sex, first-born, vitamin A supplementation, breastfeeding status, BCG vaccination, treatment sought for fever/cough, low birth weight, maternal age, maternal education, shelter index, drinking water source, household smoking, crowding, urban-rural status, rainy season and country.
†The interaction test MEPI-ARI by child age in years (continuous) was significant at p<0.001.
‡For the subanalysis per region and child's age, a significance level of p<0.006 was maintained to correct for multiple testing.
§The interaction test MEPI-ARI by country was significant at p<0.001.
¶Regions with corresponding countries and survey years: South Asia (Afghanistan 2015, India 2015), Southeast Asia (Myanmar 2015), Western Africa (Benin 2017, Ghana 2014, Guinea 2018, Liberia 2013, Mali 2018, Nigeria 2018, Senegal 2017), Eastern Africa (Burundi 2016, Ethiopia 2016, Kenya 2014, Malawi 2016, Rwanda 2014, Zimbabwe 2015, Uganda 2016, Tanzania 2015), Central Africa (Chad 2014, Congo Democratic Republic 2013), Southern Africa (Lesotho 2014, Namibia 2013).
**P-values in bold are significant.
aOR, adjusted OR; ARI, acute respiratory infection; MEPI, Multidimensional Energy Poverty Index; n, total number of cases.

95% CI 1.05 to 1.09) and Central Africa (aOR 1.10; 95% CI 1.04 to 1.16).

DISCUSSION

Our large cross-sectional, multicountry study showed a positive association between multidimensional energy poverty and ARI among children under 5 years of age. Our study also demonstrated that biomass cooking fuels, lack of access to electricity and lack of entertainment, education and household appliances are associated with increased odds of ARI. The results of this study reaffirm the critical role of improving the accessibility and affordability of modern energy services for households to address the burden of respiratory diseases among children in LMICs.

Our results are consistent with previous studies that used other proxies for households' access to modern energy services, such as electricity access, and its effect on health outcomes of children.[31 32] In addition, our study extends the evidence stemming from a comparable study based solely on DHS data from Uganda, by confirming the association between multidimensional energy poverty and ARI across 22 LMICs.

A large body of research confirms the association, observed in this study, between the MEPI indicator using biomass for cooking and ARI in children under 5 years of age.[26 33 34] Likewise, a number of studies have reported a positive association between indoor air pollution and ARI among children.[11 33] Contrary to expectations, this association was not evident in our study. A modified indicator was used for indoor air pollution to deal with missing values, which may affect its accuracy. Further research into the role of indoor air pollution to capture multidimensional energy poverty is warranted.

The association between the MEPI indicator electricity access and ARI, observed in this study, is also confirmed by a recent review on the link between electricity and health in LMICs. Besides lowering the need for polluting fuels, access to electricity is considered to affect respiratory disease through increased wealth, improved sanitation and hygiene practices and increased exposure to health information.[32] The negative association between the MEPI indicators entertainment/education and household appliance ownership and ARI in this study confirms the importance of overall improvement in family wealth. To illustrate, television and radio ownership improve exposure to environmental and health information for caregivers and their children.[35] The MEPI indicator telecommunication ownership could be associated with ARI through similar patterns. Further research is needed to confirm this theory.

The key contribution of this study is the use of the MEPI as a proxy for household deprivation in modern energy access, and its association with ARI among children across 22 LMICs. This study, therefore, adds to the existing knowledge on the association between energy poverty and ARI in children in LMICs, by adopting a multidimensional perspective that integrates energy affordability and accessibility. Not only energy accessibility (biomass cooking fuels, access to electricity), but also energy affordability (lack of entertainment/education and household appliances) is adversely associated with ARI. MEPI overlaps partially with the DHS Wealth Index, that is, constructed using a similar, but wider set of household assets and services.[15] MEPI represents a more specific set of indicators that allows to accurately measure and study energy poverty as a distinct form of poverty. This is of importance, since energy is a basic necessity for meeting fundamental needs such as cooking, heating and access to clean water. Lack of access to modern energy services hinders human development, affecting health, education and overall quality of life. In addition, energy poverty is often linked to broader socioeconomic inequalities. Certain marginalised populations may face barriers to accessing affordable and reliable energy services, which exacerbates existing inequalities. Moreover, energy poverty is closely tied to environmental sustainability. The reliance on polluting energy sources contributes to deforestation and climate change. A transition towards sustainable energy sources is therefore urgently needed.[36] A distinct index to study energy poverty helps to better understand its unique challenges and develop inclusive policies targeted at reducing energy poverty and its impact on health and well-being. The results of this study in particular encourage the design of interventions that improve (equity in) both energy affordability and accessibility. Current interventions to reduce energy poverty and its health effects in LMICs are mainly targeted at the transition to clean cooking fuels and stoves.[37] Besides the implementation of clean cooking practices, access to electricity and ownership of entertainment, education and household appliances could equally contribute to the mitigation of energy poverty and its effects on children's respiratory health in LMICs.

This study has several strengths. First and foremost, MEPI is an innovative and robust tool that was constructed according to extensive and detailed microdata stemming from DHS household surveys.[5] The dataset used in this study contained a large sample size (n=483 088) and enabled for comparison across 22 countries. Furthermore, confounders and competing risk factors were comprehensively addressed by drawing on a published causal diagram of ARI determinants.[20]

The findings of this study must be considered in the context of some limitations. The outcome of this study, ARI, was self-reported by mothers over a 2-week recall period instead. Although the consistent use of maternal-reported ARI across all surveys allowed for comparison, misclassification due to recall bias or inadvertent maternal awareness might be present. Second, the cross-sectional nature of this study did not allow for inferring causal relationships. Furthermore, studies with very large sample sizes tend to generate statistically significant results more easily, in the absence of any practical significance.[38] Bonferroni correction was applied in this study to reduce the chance of obtaining false-positive results. Nonetheless, future studies with appropriate power and corresponding sample size might be warranted. The evaluation of model fit through Nagelkerke's R^2 suggests that the independent variables in our model have a relatively limited ability to explain the variance observed in ARI. Although relevant to consider when interpreting our results, it is important to realise that ARI is a multifaceted public health issue that is difficult to capture in a single model.[39] Although the overall model fit may be poor, individual predictors may still hold considerable significance when investigating such complex and multifactorial phenomena. Finally, surveys from the past 10 years were included in this study. The current era demands for transition to clean and sustainable energy sources. The containment of surveys to the past decade ensures the adequacy of our results and its policy implications. Yet, it is important to consider that longer-term trends and historical context can also contribute to understanding the dynamics of energy poverty. The results of our study may be combined with earlier studies or historical data to gain a more comprehensive understanding of the long-term impact of energy poverty on respiratory infections in children in LMICs.

CONCLUSIONS

Multidimensional energy poverty is associated with greater odds of ARI in children under 5 years of age living in 22 LMICs. In particular, using biomass for cooking and lack of access to electricity and entertainment, education and household appliances increased the odds of ARI. These findings justify the design and implementation of interventions that address energy poverty from a multidimensional perspective and improve both energy affordability and accessibility. Causal relationships between multidimensional energy poverty and child ARI in LMICs require further investigation.

Contributors MS initiated the study and proposed the research question. MS and AvG designed the study. MS performed the statistical analysis and designed tables and figures. DN, AvG, JY-H and SZ aided in the statistical analysis. MS wrote the first draft of the manuscript. All authors critically and equally reviewed and edited the manuscript. MS is the guarantor.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval Procedures and surveys relevant to the data used in this study have been reviewed and approved by International Coaching Federation (ICF) Institutional Review Board. ICF ensures that the surveys comply with the Human Subjects Protection Act of the US Department of Health and Human Services. Permission and data access was obtained from The DHS Programme for this study. Our secondary analyses of the data were deemed exempt from additional review according to the Dutch Medical Research with Human Subjects Law by the Erasmus Medical Center ethical review committee (ref. no. MEC-2022-0560).

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Data availability statement Data are available in a public, open access repository. All data relevant to the study are included in the article or uploaded as online supplemental information. All data relevant to the study are included in the article or available as online supplemental material. The data used in the analyses are publicly available, anonymised and geographically scrambled to ensure confidentiality. More information on DHS can be found at 'https://dhsprogram.com/ (accessed on 8 August 2022)', where survey datasets can be obtained.

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