LETTER

Women’s empowerment and household fuel use in 31 African countries: a cross-sectional analysis of households in the Demographic and Health Survey

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Abstract
Access to clean and affordable energy is vital for health, well-being, and socio-economic development. This critical service remains unrealised in many African countries. Women’s empowerment is known to promote healthcare service use, child nutrition and agricultural productivity. In Africa, however, little is known about the relationship between women’s empowerment and household fuel use, and if it varies between countries. Therefore, we assessed the cross-sectional associations between women’s empowerment and cooking fuel use in 31 African countries. We analysed individual-level data from the Demographic and Health Surveys, conducted between 2003 and 2018 (n = 264 269 [women-household pairs]). We used a novel, Africa-specific index (survey-based women’s empowerment index), including three domains of empowerment: decision-making, attitude to violence, and social independence. Hierarchical logistic regression models assessed the associations between women’s empowerment domains and the type of fuel used in the household (‘clean’: electricity, liquefied petroleum gas (LPG), biogas or natural gas; ‘polluting’: solid fuels or kerosene). Results were adjusted for household- and area-level covariates, and expressed as odds ratios (OR). The 31 country-specific estimates were combined using meta-analysis. Approximately 43 778 (14.5%) of households used clean fuels. Overall, between 12/31 and 22/31 country-level estimates showed a significant association between a one standard deviation increase in empowerment domains (higher scores indicate greater empowerment), and higher odds of using clean fuel as primary energy source for cooking. The random-effect meta-analytic estimates showed that increased empowerment was associated with higher odds of using clean fuel for attitude to violence (OR = 1.22; 95% CI: 1.12–1.33), social independence (OR = 1.34; 95% CI: 1.28–1.42), and decision-making (OR = 1.10; 95% CI: 1.05–1.15). These findings suggest that empowering women, in addition to being crucial in its own right, has potential to accelerate transitions to clean fuel in Africa, although these associations vary between countries.

1. Introduction

Cooking with solid fuels and kerosene, in an open fire or simple stoves, is a major environmental risk factor for health globally [1–4]. The World Health Organization (WHO), under its indoor air quality guidelines, defines solid fuels (coal plus biomass such as charcoal, wood, dung, and crop residues) and kerosene as ‘polluting’, and other fuels, such as electricity, LPG, biogas and natural gas as ‘clean’ [5]. These fuels are all associated with some emissions, but this binary classification is a useful way to distinguish relatively high and
low emission fuels. Incomplete and inefficient combustion of polluting fuels releases over 200 chemicals, of which >90% are respirable [1, 6]. Domestic activities, including cooking, heating and lighting contribute approximately 21% of global ambient fine particulate matter (<2.5 µm in aerodynamic diameter; PM$_{2.5}$) mass concentrations [7], and 25% of global emissions of black carbon; a major constituent of PM$_{2.5}$ and contributor to radiative forcing and climate change, as well as carbon dioxide (CO$_2$) and other gaseous emissions [8–11].

The proportion of the world’s population with access to clean cooking fuels (i.e. being able to use clean fuels as primary source of energy for cooking) was estimated to be 57% in 2014, while 43% were without such access (i.e. relying on polluting fuels) [9]. Apart from primary cooking fuels, it is well documented that some households use a combination of clean and polluting fuels in parallel (i.e. ‘fuel-stacking’) [5, 12]. Despite modest reductions in many countries since 2010, in 2017, approximately 3.6 billion people (47% of the global population) still relied on solid fuels alone (i.e. excluding kerosene) [13], with deep disparities between rich and poor, and between urban and rural dwellers [14–16].

About 82% of Africans cook primarily with polluting fuels [9, 17], of which the large majority is firewood, followed by charcoal, kerosene, dung and coal [18]. Firewood, dung, agricultural residues and other lower grade fuels are consumed widely in rural parts of the continent whilst charcoal, kerosene, LPG and clean fuels are used in urban settings [19].

In 2018, estimates suggest approximately 500 000 premature deaths [20] and more than 26 million disability-adjusted life years were lost in Africa due to polluting fuels [18]. In addition, gathering, preparing and using fuels exposes women and children to numerous risks, and reduces time available for education and other productive activities. In Africa, a woman spends an average of 2.1 h d$^{-1}$ gathering fuel [21], and spends about 3 h d$^{-1}$ close to open biomass stoves [18]. It is estimated that globally, access to clean cooking would help prevent 3.8 million premature deaths annually, primarily among women and children [14], decrease missed school days, shorten cooking time and reduce labour and time required for collecting fuel, and reduce ambient air pollution [22–24].

Earlier research from developing countries established the concept of the ‘energy ladder’ [25]. As income rises, households move away from traditional fuels like wood, crop wastes and dung to adopt intermediate fuels like charcoal, coal and kerosene, and then to modern, less polluting fuels, including gas and electricity [26]. However, it has been demonstrated that higher income does not necessarily move households ‘up the ladder’ [2, 27]. Other factors may contribute to fuels used in the household [28–30]. Women are principally responsible for collection and use of fuel in many low-income countries, and women’s empowerment has been identified as key to accelerating progress towards the sustainable development goals (SDGs). In Africa, despite gender imbalances in labour, resources, and decision-making that favour males, women can play a role in the implementation of clean fuel projects [14, 31–33], because they are socially influential and create networks that may enhance adoption of clean fuel [34–36].

Women’s empowerment is a complex, multidimensional concept, with no standard definition [37, 38]. Notwithstanding this, definitions of women’s empowerment generally refer to women’s individual and/or collective capacity to have power to control their own lives (both within and outside the home), ability to influence the direction of social changes (nationally and internationally), and access to opportunities and resources [39–41]. Empowerment of women and girls is both a stand-alone goal, and a key facilitator of development across several important areas (e.g. family planning, access to nutrition, and availability of health care) [42–44]. However, empowerment is challenging to measure and track over time. Indices based on routine surveys have been used previously, but have been restricted to snapshots of individual countries, limiting comparisons within- and between-countries over time, among other methodological limitations [37, 45, 46].

A large amount of empirical research has been undertaken in low- and middle-income countries on solid fuels and health over the past several decades, such as the crucial and sustained work of Professor Kirk R Smith (1947–2020) [47]. There is also a substantial body of research that focused on socio-economic and other determinants of fuel use and/or switching to cleaner fuels; some of which is summarized in literature reviews [28, 29, 48]. These important contributions have helped to shape understanding and highlight the complexity of this field. However, the large majority of studies were done in a single country or area within a country; for example, only 2/32 studies reviewed by Lewis and Pattanayak [28] included more than one country.

In this study, we sought to capitalise on the recent availability of externally-validated empowerment index for Africa (survey-based women’s empowerment index [SWPER]), which has improved on previous indices and allows between-country comparisons, to estimate women’s empowerment [37]. The two aims of our study were: (a) to quantify the associations between different dimensions of women’s empowerment and household fuel use at national-level across Africa; and (b) to assess the combined association of these national estimates across the African continent via meta-analyses.
2. Methods

2.1. Data sources
We used data collected by the Demographic and Health Survey (DHS) in African countries. The DHS is a major and long-running source of international public health data, and its scope and methods are extensively documented [49]. The survey design is based on a probabilistic, stratified two-stage sampling plan that defines strata by administrative regions and by rural-urban areas within each region [49]. Forty-six countries in Africa have conducted at least one round of DHS surveys, and rounds are repeated approximately every 5 years. We included the most recent survey for each country, which corresponded to a range of 2003–2018. A total of 33 countries were included, based on availability of cooking fuel information, variables used by the SWPER [37], and other variables of interest.

All DHS surveys are approved by ORC Macro Institutional and by relevant ethical review boards in each country. We obtained permission from ICF-DHS program to use the DHS data, accessed online (http://dhsprogram.com). Our study was deemed exempt from additional ethical review by The University of Queensland Office of Research Ethics (approval: 2020001013).

2.2. Outcome variable
The DHS surveys record only the primary fuel type used for cooking in each household, and do not capture multi-fuel stacking or non-cooking fuel sources. The primary cooking fuel was the outcome variable in our analyses, and all references in the text to household fuel use refers to that variable. We then created a binary outcome, based on WHO definitions in their indoor air quality guidelines [5], comprising clean fuels (including electricity, LPG, natural gas and biogas) and polluting fuels (kerosene, coal, charcoal, wood, dung, crop residue, grass, shrubs and straw). The binary outcome was our primary focus in the analyses; we also did sensitivity analyses using an outcome based on published emission rates of PM$_{2.5}$ and carbon monoxide (CO) (the two main pollutants used to quantify cooking emissions in field studies), as a more detailed indicator of relative emissions [1, 10, 50]. For example, compared with other solid fuels (wood, agricultural crop, dung, straw, shrubs and grass), coal and charcoal generally have lower PM$_{2.5}$ and CO emission rates [51, 52]. We initially used four categories, including (from lowest to highest emitting) clean fuels (electricity, LPG, natural gas and biogas), kerosene, transitional fuels (coal and charcoal) and other solid fuels (wood, dung, agricultural crop, straw, shrubs and grass). This was subsequently reduced to three (by combining kerosene, coal and charcoal) to improve model convergence for country-specific estimates.

2.3. Exposure variable
Our main exposure variables were from the SWPER index, which is based on existing individual-level DHS data collected among women aged 15–49 years, and covered three domains of women’s empowerment, and which has demonstrated external and convergent validity [37]. Following the methods described by the SWPER’s developers, we applied principal component analysis (PCA) to 15 women’s status indicator variables; the index is based on DHS data, but was not linked to the main DHS data set at the time of our study [37]. Prior to PCA, responses to variables were categorized so that higher values indicated greater empowerment, to assist with interpretation of associations (table S1 (available online at stacks.iop.org/ERL/16/025012/mmedia)). Three components were retained, as they explained 25%, 14% and 11%, respectively, of the total variability explained by all 15 principal components, which were attitude to violence (i.e. respondents’ attitude towards violence against women), social independence, and decision-making, respectively. These components, and the items they comprised are presented in the supplementary file (tables S2 and S3).

We followed methods analogous to those of Ewerling et al [37] to compute women’s empowerment scores. Each index was standardized; a detailed explanation of the equations used to calculate the standardized scores is in the supplementary file (page 4 S4).

2.4. Statistical analysis
Due to the multistage cluster sampling approach used by the DHS program, the data form a conceptual hierarchy in which women (first level), are nested within a household (second level) and households are nested within a cluster (third level). It is possible that households from the same cluster may be more correlated than those in other clusters, due to the effect of contextual conditions such as availability and accessibility of clean fuel, its price, and level of connectedness of clusters to infrastructure (road, transportation, electricity grid, etc). We therefore used hierarchical (two-stage) binary logistic regression (main analysis) and multinomial logistic models (sensitivity analysis using three fuel categories), with cluster-level random effects (i.e. to allow for potential differences between clusters) using melogit and gsem commands in STATA, respectively. Because each woman was from a specific household, levels one and two of the hierarchies were merged to improve model convergence and interpretability. A similar approach was used by a previous study [53]. Further details are in the supplementary file (page 5 S5). The weighted prevalence of clean and polluting fuels and independent variables in each survey were calculated, incorporating the DHS sampling weight, using the svyset command.
For each country, we first fitted an empty model (model 1) to assess random variation in the intercept and the intra-cluster correlation coefficients (ICC), which helps to evaluate the extent of the cluster variation in fuel use. Second, a crude model (model 2) was fitted to assess the association between empowerment and fuel use (i.e. adding each domain into empty model). Third, an adjusted model (model 3) was fitted to examine the independent effect of each empowerment domain controlling for other household-level variables that were not already included as part of in the SWPER index, and which we considered to be relevant covariates given our exposure and outcome of interest. For example, household wealth status is associated with household fuel use [28, 54, 55], and we followed DHS methods to derive a wealth index that was comparable across the countries in our sample [56]. Also, the sex of the household head and family size [26, 57–59] were included. Finally, model 4 was fitted to extend model 3 by accounting the potential differences in availability of cooking fuel [14, 60] by adding urban/rural location of each survey cluster and night-time light at the clusters; a proxy for regional wealth, degree of electrification of dwellings, and infrastructure [61]. The coefficients of non-empowerment covariates in these models were used for comparison with those of empowerment (i.e. as an indicator of their relative importance) for a subset of seven countries that spanned a range of fuel types and socioeconomic status across Africa (table S5).

Estimates were presented as adjusted odds ratio (aOR) and relative risk ratio (for multinomial models) with 95% CI, and expressed per one standard
Table 1. Details of the 33 countries, year, total sample size, and number of households using clean fuel DHS data collected from 2003 to 2018.

| Country                       | Survey year | Number of households | Households using clean fuel (n [%]) |
|-------------------------------|-------------|----------------------|-------------------------------------|
| Angola                        | 2016        | 7725                 | 3534 (44.2)                         |
| Benin                         | 2018        | 10 521               | 427 (4.1)                           |
| Burkina Faso                  | 2010        | 12 459               | 384 (3.1)                           |
| Burundi                       | 2017        | 9 349                | 17 (0.2)                            |
| Cameroon                      | 2011        | 9 242                | 1 284 (13.7)                        |
| Chad                          | 2015        | 12 761               | 344 (2.7)                           |
| Comoros                       | 2012        | 2990                 | 123 (4.1)                           |
| Cote d’voire                  | 2012        | 6038                 | 583 (9.4)                           |
| Democratic republic of Congo  | 2014        | 11 172               | 185 (1.6)                           |
| Egypt                         | 2005        | 16 359               | 16 310 (99.4)                       |
| Eswatini                      | 2007        | 1848                 | 636 (34.2)                          |
| Ethiopia                      | 2016        | 9297                 | 721 (7.7)                           |
| Gabon                         | 2012        | 4460                 | 3 180 (70.0)                        |
| Ghana                         | 2014        | 5269                 | 997 (18.9)                          |
| Guinea                        | 2018        | 7696                 | 116 (1.5)                           |
| Kenya                         | 2014        | 18 213               | 1110 (6.0)                          |
| Lesotho                       | 2014        | 3355                 | 1169 (34.8)                         |
| Madagascar                    | 2009        | 11 484               | 102 (0.9)                           |
| Malawi                        | 2016        | 15 630               | 256 (1.6)                           |
| Mali                          | 2018        | 7805                 | 126 (1.6)                           |
| Morocco                       | 2004        | 8253                 | 992 (11.7)                          |
| Mozambique                    | 2011        | 8762                 | 414 (4.7)                           |
| Namibia                       | 2013        | 3592                 | 1518 (41.3)                         |
| Nigeria                       | 2018        | 27 748               | 2643 (9.5)                          |
| Rwanda                        | 2015        | 6798                 | 16 (0.2)                            |
| Senegal                       | 2011        | 10 278               | 1506 (14.6)                         |
| Sierra Leone                  | 2013        | 10 584               | 6 (0.1)                             |
| South Africa                  | 2016        | 2706                 | 2 198 (80.6)                        |
| Tanzania                      | 2016        | 7571                 | 34 (0.6)                            |
| Togo                          | 2014        | 6183                 | 296 (4.8)                           |
| Uganda                        | 2016        | 10 581               | 61 (0.6)                            |
| Zambia                        | 2014        | 7219                 | 539 (7.5)                           |
| Zimbabwe                      | 2015        | 5726                 | 1952 (33.6)                         |
| Total sample                  |             | 302 786              | 43 778 (14.5)                       |

Clean fuel: electricity, liquefied petroleum gas, natural gas and biogas

3. Results

3.1. Descriptive results

Figure 1 summarises the selection of countries, and the total sample included in the analysis. Table 1 presents descriptive statistics of the 33/46 countries included in our analysis, based on availability of fuel use, empowerment indices and covariates, and year of survey, and clean fuel use. Briefly, 302 786 households in the 33 countries were included in the descriptive analysis. Overall, clean fuel was the primary cooking fuel used by 43 778 (14.5%) households. Egypt (99.4%), South Africa (80.6%) and Gabon (70.0%) were countries with highest number of households that used clean fuel. Sierra Leone (0.1%) and Rwanda (0.2%) were countries with fewest households using clean fuel, and were not included in subsequent logistic regression models due to the small number of observations across categories of the outcome variable. Figure 2 shows the distribution of main fuel types used for cooking. Overall, the dominant clean

fuel was LPG (9.6%), followed by electricity (3%) and natural gas (1.6%). The majority of African households (61.6%) used wood as their primary energy source for cooking (figure 2).

Of the 302,786 households in 33 countries for which cooking fuel information was recorded, excluding Sierra Leone (n = 10,682) and Rwanda (n = 6,825) left 285,279 households in 31 countries. Of those, 264,269 households, representing the same number of individual women (i.e. there was one respondent per household) also had all items required to develop women’s empowerment indices. Table 2 presents descriptive statistics of women’s empowerment domains and other household and cluster-level characteristics.

### 3.2. Country-level associations between women’s empowerment and fuel use

We found that a one standard deviation increase in social independence was significantly and positively associated with using clean fuel as primary energy source for cooking in 22 out of 31 countries (figure 3). Of those, Ghana (aOR = 1.77; 95% CI: 1.59–1.97), Mozambique (aOR = 1.72; 95% CI: 1.45–2.04) and Madagascar (aOR = 1.63; 95% CI: 1.27–2.08) were the countries where social independence was associated with the greatest odds of using clean fuel as primary energy source for cooking. For the nine remaining countries, aORs were consistently above 1, but did not reach significance at the 5% level.

The empowerment dimension that covered women’s involvement in decision-making ability was significantly associated with using clean fuel in 13 out of 31 countries (figure 4). A one standard deviation increase in decision-making was associated with higher odds of using clean fuel as primary energy source for cooking in Malawi (aOR = 1.52; 95% CI: 1.21–1.91), Lesotho (aOR = 1.41; 95% CI: 1.19–1.66) and Egypt (aOR = 1.38; 95% CI: 1.03–1.80). Null associations (i.e. not statistically significant at the 5% level) were observed for the remaining countries, with the exception of Morocco (aOR = 0.81; 95% CI: 0.71–0.91).

Women’s attitude to violence was positively associated with the use of clean fuel as primary energy source for cooking in 12 out of 31 countries (figure 5). Madagascar (aOR = 2.14; 95% CI: 1.00–4.61), Ghana (aOR = 1.79; 95% CI: 1.41–2.28) and Egypt (aOR = 1.61; 95% CI: 1.21–2.13) were associated with the largest increase in the odds of using clean fuel as primary energy source for cooking per one standard deviation increase in the attitude to violence dimension. Estimates and the associated CIs for all countries included in the meta-analyses are presented in the supplementary file (table S4).

The empty models suggested that odds of using clean fuel as primary energy source for cooking was accounted for by between-cluster variation, which was indicated by large ICC in all countries, which supported the incorporation of cluster-level random effects in the other models. AIC and BIC values were...
Table 2. Descriptive statistics of women’s empowerment domains, household and cluster characteristics in 31 African countries, DHS data collected from 2003 to 2018. Note: values of women’s empowerment domains were standardized, with mean of 0 and SD of 1.

| Variables | Mean | SD | Frequency (%) |
|-----------|------|----|---------------|
| Empowerment dimensions (n = 264 269) | | | |
| Attitude to violence | 264 269 | | |
| Social independence | 264 269 | | |
| Decision-making | 264 269 | | |
| Age of women in 5 years group | | | |
| 15–19 | 19 452 (6.8) | | |
| 20–24 | 48 913 (17.2) | | |
| 29–29 | 59 383 (20.8) | | |
| 30–34 | 51 726 (18.1) | | |
| 35–39 | 44 895 (15.7) | | |
| 40–44 | 33 802 (11.9) | | |
| 45–49 | 27 108 (9.5) | | |
| Highest level of education women attended | | | |
| No education | 113 609 (39.8) | | |
| Primary | 92 457 (32.4) | | |
| Secondary | 67 062 (23.5) | | |
| Higher | 12 151 (4.3) | | |
| Household wealth index | | | |
| Poorest | 62 228 (21.8) | | |
| Poorer | 57 851 (20.3) | | |
| Middle | 55 482 (19.5) | | |
| Richer | 54 735 (19.2) | | |
| Richest | 54 907 (19.2) | | |
| Place of residence | | | |
| Urban | 96 022 (33.7) | | |
| Rural | 189 257 (66.3) | | |
| Gender of head of household | | | |
| Male | 242 781 (85.1) | | |
| Female | 42 498 (14.9) | | |
| Family size (no of household members) | 6.5 | 4.0 | 285 279 |
| Night-time lights (composite cloud-free radiance values)* | 0.6 | 1.0 | 285 279 |

* Log transformed.

The meta-analytic OR estimate showed that a one standard deviation increase in each domain of empowerment was associated with higher odds of using clean fuel as primary energy source for cooking (figures 3–5): social independence (pooled OR = 1.34; 95% CI: 1.27–1.41), attitude to violence (pooled OR = 1.22; 95% CI: 1.12–1.33), and decision-making (pooled OR = 1.10; 95% CI: 1.05–1.15).

3.4. Alternate fuel categories
In sensitivity analyses using three fuel categories, Egypt and Morocco were excluded because of insufficient observations for the categories; our analyses were based on the remaining 239 675 households in 29 countries. The results were largely consistent with our main country-level and meta-analysis estimates. Compared with the most polluting fuels (wood, dung, crop waste, grass, straw or shrubs), increases in each empowerment domain were generally associated with higher odds of primarily using less polluting (kerosene, coal and charcoal) or clean fuels (electricity, LPG, natural gas and biogas). Forest plots with country and pooled estimates for each domain and fuel type are in the supplement (figures 4(a)–(f)).

lowest for model 4 (i.e. the model that incorporated empowerment domains, household- and cluster-level characteristics), suggesting it was appropriate for our analyses (table S5).

Of other covariates, household wealth status had a notably prominent positive association in models 3 and 4 for most of the seven countries we assessed, while there was variation in the association for the remaining covariates across countries (table S5). For example, a one standard deviation increase in household wealth index had an approximately five- to ten-fold greater OR than the same increase in empowerment domains in models 3 and 4.

3.3. Meta-analysis of associations between women’s empowerment and fuel use
Substantial country-to-country variation in associations was observed. $I^2$ statistics indicated the association between each domain of women’s empowerment and use of clean fuel had pronounced heterogeneity between countries: attitude to violence ($I^2$: 73%; $p < 0.001$), social independence ($I^2$: 71%; $p < 0.001$), and decision-making ($I^2$: 62%; $p < 0.001$) (figures 3–5). We therefore focus on the results of random effects meta-analysis.
4. Discussion

The SDGs have an explicit focus on energy, specifically, goal seven aims to ensure access to affordable, sustainable and modern energy for all by the year 2030 [14]. Household energy, as a goal, is not only an end in itself, but it is also a means through which to accelerate the progress of other SDGs [9]. Our analysis of the DHS surveys conducted between 2003 and 2018 in 33 African countries showed that more than 85% of households were primarily reliant on polluting fuels such as wood, charcoal, coal, kerosene, dung and crop waste for cooking. Despite important progress, it seems unlikely that many African counties will meet SDG targets on the transition to clean fuel, and highlighting the need for accelerated investment in clean fuel and mitigation policies.

Another pivotal SDG, which is aimed at accelerating sustainable development, is the promotion of women’s empowerment and gender equality [17]. Our results suggest that components of these two SDGs (i.e. women’s empowerment and clean household energy) have a number of interesting associations in the countries we assessed. Greater empowerment of women across the three dimensions of the SWPER index (attitude to violence, social independence, and decision-making) was associated with higher odds of using clean fuel as primary energy source for cooking in the household in 12/31, 22/31 and 13/31 countries, respectively. Significant between-country variation was observed, which is more suggestive of underlying heterogeneity than sampling error. Such heterogeneity could, for example, reflect differences driven by cultural
practices affecting women's status, use of fuels, or both. We therefore used random effects in the overall meta-analysis.

The multi-country scope of the SWPER index, and validity across Africa, allowed us to compare country-level associations between empowerment and fuel use, while controlling for household and area-level factors, such as night-time lights—a proxy for regional wealth, degree of electrification of dwellings, and infrastructure—in our models as an effort to account for differences in access to and use of fuels. The results show that associations between women's empowerment domains and household fuel use are not universal. For the 31 African countries overall, however, our meta-analysis suggests positive associations between all empowerment domains and primary use of clean fuel in households.

Fuel use by households is driven by a complex interaction of various social, cultural and environmental factors [19, 55, 65, 66], and women are often responsible in acquisition and use of fuel in many societies. Despite the associations we observed for empowerment, the effects were markedly smaller than those for a comparable increase in household wealth index in seven representative countries. This suggests that while wealth is still the dominant driver of fuel use, women's empowerment has a relatively modest but key role because of its importance in other areas, unrelated to fuel use. Our findings are generally consistent with the literature, in terms of the prominent, albeit heterogeneous, role of socio-economic and cultural determinants of fuel use [28]. This may reflect, at least in part, that women are socially influential in creating networks that enhance adoption of less polluting household energy [65, 67], and are more likely purchase and use clean stoves more when they receive information from friends [68, 69]. In many African countries, the social and
cultural norms are different, which could, in turn, have greater influence on adoption and use of clean household fuel. This could be one reason for low penetration of clean energy and modern stoves in the continent [70]. Supporting evidence also showed that in areas where access to clean fuel is not an issue, barriers of awareness and social acceptance remain important for a wider adoption of cleaner fuel [28, 71]. This could also be associated with women's empowerment in that when women are socially independent, they can participate in social organizations and share knowledge about the benefit of clean fuel. Further, women who have better decision-making ability in the household could allocate resources and purchase or adopt clean fuel.

Our study makes several contributions to the existing body of knowledge. This is the first comprehensive, multi-country African-based study attempting to investigate the relationship between women's empowerment and household energy use at continental-scale, within the countries participating the DHS. Both energy and women's empowerment are key global developmental agendas, and also a means to accelerate other SDGs. The use of an Africa-SWPER enabled valid between-country and overall analyses. We used a multilevel (two-level) binomial and multinomial logistic regression techniques, in an effort to account for the cluster-level random effects. Ensuring clean energy access for households in Africa will not be achieved without more gender responsive programs, so that these results open avenues for policy makers to further investigate these gaps and initiate measures to accelerate progress, in line with the SDGs.

There are several limitations to our analyses. Despite some studies suggesting that more empowered
women play greater role in addressing other public health priorities like family planning and nutrition [43, 44], there could be other factors (e.g. fuel accessibility and use policies) confounding or mediating the associations we reported. The DHS collects only one fuel type, which is dominant, used for cooking (does not take fuel stacking into consideration) [72], and while many households in Africa use polluting fuels for heating and lighting, DHS does not collect information on fuel used for these purposes. As a result, the number of households using polluting fuels is likely to be under-estimated. Another important limitation is that most of woman’s status indicators collected by the DHS, and the SWPER index, were applicable to only married or partnered women, because of this our analyses did not include single, widowed, divorced, and separated women. Empowered women are not necessarily married or in union, and this could have led to downward or upward bias in our estimates, depending on the number and location of such individuals. We treated fuel use as the dependent variables, because it has an intuitive interpretation that is consistent with most other studies of socio-demographic determinants of fuel use [28], or choice [73], or switching [58]. It is possible that clean fuel may lead to empowerment (e.g. women spending more time on educational and income-generating activities) [38, 74]. Finally, although 27 out of 31 countries were surveyed between 2010 and 2018, there is potential residual confounding due to the different periods during which countries were surveyed.

5. Conclusions

In summary, our findings suggest that empowering women, as well as being important in its own right, is associated with use of cleaner cooking fuels across the 31 African countries we analysed as a whole. However, these associations are not uniform at the country-level, and positive associations with dimensions of empowerment were observed in as few as 12/31 countries. Cleaner fuels have lower CO₂ and black carbon emissions, which is relevant to SDG 13 on climate change and its impacts. Our findings require further corroboration, but may highlight a means with which to accelerate progress towards three crucial SDGs contemporaneously.

Data availability statement

The authors used publicly available data from the Demographic and Health Survey (DHS), which can be accessed upon formal request to Measure DHS, ICF International. Further codes and formulas that were used to produce these results are available upon request from the authors.

The data that support the findings of this study are openly available at the following URL/DOI: www.dhsprogram.com/data/dataset_admin/login_main.cfm.

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Contribution

D B O and L D K designed the research. D B O obtained the data. D B O and L D K conducted the data analysis and interpretation. D B O wrote the draft manuscript, and all authors (L D K, I A Y and D L G) provided critical intellectual input into revising it.

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