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Research Article

Household-Level Effects of Energy Insecurity on Welfare in Southern Africa: A Malawian Case Study

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ABSTRACT. The debate of energy security has, over the past decades, centered on supply factors within the energy policy framework in the public policy discourse. Much more empirical evidence is required to fully understand the household-level effects of energy security on development outcomes. This paper explores the characteristics of the households that face energy insecurity and also analyze the effects of energy insecurity on household welfare using the recent data from the Malawi Fourth Integrated Household Survey(IHS4) 2016-2017. Overall, 42.58% of Malawian households were found to be energy insecure and the study findings show that the energy insecure were a heterogenous group compared to the energy secure. The heterogeneity exist because of differences in demographics (likely to be advanced in age, likely to be females, less likely to have a household head with formal education); socioeconomic status (likely to be poor, had low wealth levels); geography (likely to be rural dwellers in the central and southern parts of Malawi); housing and dwelling status (less likely to be renters, less likely to be found in permanent or semi-permanent buildings that have iron sheets and cement floor). Additional results from econometric analysis showed that energy insecure households reduced their food consumption by 2.3% for each 1% unit increase in the share of the energy costs in their total household budget. Similarly, on the education outcome, the energy insecure households reduced their education expenditure by 3.6% for each 1% unit increase in the share of the energy costs over the total household expenditure. These findings show that energy security plays a key role towards improvement of household welfare in general as this might have short term and long-term negative implications on human capital development.

Keywords: Energy insecurity; household welfare; Malawi; Southern Africa

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1. Introduction

The total installed generation capacity for grid electricity in Malawi (around 361MW) is not adequate enough to meet the current demand for both industrial and domestic use (over 1000 MW), making it one of the energy –stressed countries in the Southern African region (GoM, 2018; GoM, 2017). For instance, the in-country study confirmed low uptake of Liquid Petroleum Gas (LPG) as a cooking fuel, with only 2% of the urban population that was monitored using the fuel despite being the most cost-efficient cooking fuel (Practical Action, 2017). So far, there is scanty literature in the country to show how the energy burdens are impacting household welfare amidst climate change, population growth and in view of growing urbanization due to secondary towns and cities. A study by Maganga *et al.* (2015) revealed that location of residence, education level of household head, income, and age of household head were major significant factors in determining the probability of household's choice of cooking fuels. However, their study only focused on the non-price factors that determine the probability of household cooking energy choices but left out the other important aspect of energy use patterns such as home lighting. But how many households are energy insecure and to what extent does energy insecurity affect household welfare in Malawi to achieve the sustainable development goals number 7 and 12 which demand inclusive access to clean energy for all and responsible consumption and production respectively? This remains a major public policy research question that demands more empirical research.

This study explored the characteristics and assessed the effects of energy insecurity on household welfare in a developing country context. It used data from the Malawi Fourth Integrated Household Survey (IHS4) 2016-2017, which is part of the World Bank's Living Standards

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Measurement Survey (NSO, 2017). Specifically, the study examined the household welfare (food consumption and education expenditures) of Malawian households to understand which among them were burdened and greatly affected by high energy expenses to explore prospects for renewable energy sources such as solar to ensure energy security at household level (Ezema et al., 2016; Ahmad & Byrd, 2013). Therefore, this paper is empirically relevant in such a way that it provides insights into which type of households are highly burdened with energy costs from poverty and education policy perspectives. It is timely and points to policy gaps especially in this era of Covid 19 pandemic and calls for policy measures to promote diffusion and adoption of modern commercial fuels such as LPG, solar or any of other renewables to diversify energy sources thereby increasing energy security. Renewable technologies such as solar photovoltaics, windmills, LPGs, and micro hydro power stations are associated with improved range of socio-economic benefits leading to reduced environmental pollution as well as opportunity costs leading to improved development outcomes for women and children in the long run (Shoaib & Ariaratnam, 2016). The major setback for these modern fuel sources lies in the initial start-up costs for connections in case of grid electricity and equipment, and stoves for LPG as such most poor households are not able to adopt. Household decision making process on energy consumption and fuel choices is complex since it is hinged on a wide array of factors encompassing economical, technical, social and cultural reasons which vary depending on the study context (LV *et al*., 2018).

Taking the case of Malawi, its annual urbanization rate increased from 3.7 to 3.9 percent with around 2.8 million people living in urban areas between the years 1998 to 2008 and is classified to be modest compared to other African countries (World Bank, 2016). In addition, the World Bank report further shows that Malawi had moderate annual net migration inflow of roughly 14,000 working-age migrants that relocated to cities and towns from the period of 2006 to 2010 that resulted to modest urban population growth. This rate and pace of urbanization presents a golden opportunity to Malawi to capitalize on the multiplier effects that come with urban agglomeration especially in the promotion of renewable energies such as LPG and Solar and other clean energy sources to reduce energy burdens in homes. So far, the four Malawian cities (Lilongwe, Zomba, Mzuzu, Blantyre) contributed 33 percent to the national growth domestic product (GDP) despite having a lower percentage towards the total population which is around 13 percent. On the contrary, the rural parts consist of 85 % of the Malawian population but offer only 62 percent towards the national GDP (Manda, 2013). In addition, secondary towns inhabit almost 3 percent of the total population with a 6 percent contribution to national GDP which is remarkable. As of 2018, the Malawian population had increased from 13,077,160 in 2008 to 17,563,749 in 2018 with 16 percent of the population residing in the urban areas (NSO, 2019). This simply shows that the urban economy has a lot to offer in terms of making significant impact towards the national development growth agenda thereby realizing sustainable development goal outcomes.

On the other hand, the trend of growing secondary towns has forced rural households in Malawi to live in close proximity with urban households in smaller towns. This has caused some rural households to adapt to land scarcity and deforestation as a result of rural-rural and urban-rural migration patterns (Stringer *et al.,* 2009). So, what is pertinent in this research study is to get understanding in terms of how energy security is shaped by this pattern of urbanization and migration which lead to both direct and indirect influences on household welfare and decision-making processes for both urban and rural residents (Tchereni, 2014; Chikhungu *et al.,* 2014).

The existing literature highlights multiple alternative metrics and several dimensions that are used to capture the extent and nature of the energy burden problems globally as conceptualized in Fig.1. A summary of all key literature regarding these alternative metrics and dimensions to capture energy burden problems is presented in Table 1.

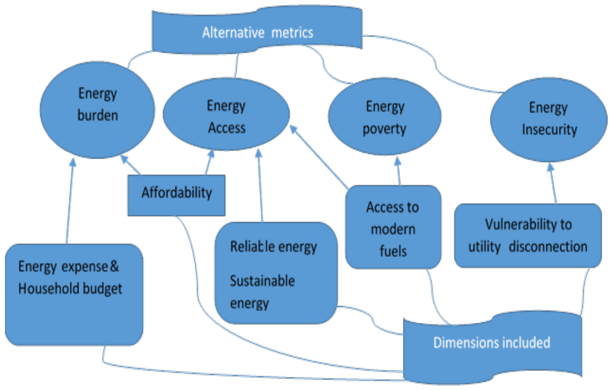

Fig 1. Scope of energy burden and related definitions.
Source: Adapted from Brown *et al.* (2020).

At international level, energy poverty has simply been referred to as lack of access to energy services.Some scholars over the past decades have conceptualized energy poverty as a commodity basket to satisfy basic home energy requirements such as lighting, cooking and entertainment plus other special energy needs and is usually understood arbitrarily (Khandker et al., 2012). To date, there is no universal consensus regarding this “energy poverty construct” and still varies depending on culture, climate and country contexts (Pachauri & Spreng, 2011& 2004; Bilal & Szirmai, 2010; Foster *et al.,* 2000). Recently, the energy poverty concept has evolved into several definitions by different scholars making it possible to be investigated in both developed and developing countries since it affects quality of life and welfare (Maxim *et al.,* 2016; Pye *et al.,*2015). Nussbaumer *et al.* (2012) formulated a Multidimensional Energy Poverty Index (MEPI) that allows for a number of energy components that relates to cooking, lighting entertainment and communication. One of the limitations of this index is that it only concentrates on specified segment of population especially those with inadequate modern energy access and heavy users of dirty fuels such as wood and kerosene (Phoumin, 2019a). Generally, weighing and aggregation to construct the indices (i.e. energy poverty index, energy development index, MEPI) still remain a challenge. For instance, the World Bank Multiplier Framework (MTF) Index is highly contested because it is indeterminate why equal weights are assigned to different household energy usage i.e. productive use having same weight as community energy usage (Culver, 2017; Groh*et al.*,2016; Mirza & Szirmai, 2010). Barnes *et al.* (2010) measured energy poverty in a more intuitive way using a 10% energy share cut off point threshold as a way how it may affect other household basic necessities such as food. However, there are still outstanding issues that need to be addressed to have a universal consensus towards energy poverty of which some include need for a proper rating scale so that income composition and selected threshold properly guide the targeted study population (Moore, 2012). Furthermore, energy poverty is also highly linked to and dependent on non-economic factors such as culture and individual privacy coupled with both temporal and space dynamic dimensions (Thomson *et al.*, 2017). Energy access terminology has been commonly used by international agencies especially the United Nations who adopted Sustainable Cities and Communities Goal (SDG 11) and Sustainable Development Goal 7 (SDG7) (UNDP, 2017; Barnes *et al.,* 2010). SDG 11 aims at ensuring provision of adequate and affordable utility basic services whilst the SDG 7 emphasizes at provision of affordable, reliable, sustainable and modern energy services to all by 2030.

Regarding household energy burden, Colton (2011) classified "energy poor households" as those households having a share of energy costs of greater than 6 % to their total income. For this scholar, the reference point was that a household was supposed to spend less than 30% of its budget on housing cost whilst expenditure on utilities is supposed to be less than 20%. Furthermore, other scholars in United States of America (USA) are still proposing a variety of thresholds. For instance, Cook & Shah (2018a) classified energy stressed households as those with energy burden of about 4 to 7%; energy-burdened households as those having energy burden of about 7 to 10% and lastly the energy-impoverished households were households that had energy burdens of more than 10%. In other words, energy burden refers to the share of household income that is spent on the energy costs and is usually the largest among the poor (Drehobl & Ross, 2016).

The other new construct by Berry *et al.* (2018) defines "energy insecurity" as a situation whereby a household is not sure of possibility of being able to pay its utility bills, that may lead to temporary or permanent utility disconnection towards the energy services. Elnakat *et al.* (2016) and Ross *et al.* (2016) noted that energy security incidence varies depending on study context. The International Energy Agency (IEA) defines energy security as the uninterrupted availability of energy sources at an affordable price (Ayoo 2020).Since there are many definitions, for consistency purpose, this study adopted the definition of household energy insecurity as spending greater than 10 % of household income on energy expenses (Phoumin, 2019; Hernandez *et al.,*2016; Hernandez *et al.,*2014). In other words, this paper adopted the approach of using 10% threshold of household energy expenditure as an energy insecurity cut-off point. However, this paper did not employ the other approach of using the minimum 600KWh/ year household electricity consumption threshold as was the case in the Cambodia study by Phoumin (2019) or 2125 KWh in the Guatemala study by Foster *et al.* (2000) to avoid restricting the analysis to grid connected households.

Despite much interest in energy security, there is limited empirical research documenting household-level effects of energy insecurity across different socio-economic groups especially in a developing country context using large sample size from the ongoing World Bank Living standards survey datasets that are making data accessible and open to both scholars and development practitioners. To the knowledge of the authors, this is one of the few energy studies that examine household welfare effects of energy insecurity within the developing country contexts using large sample data. As such, this study fills the existing gap in the literature and justifies the need to find innovative ways of improving access and affordability of both clean and energy efficient technologies to reduce disparities between the rich and the poor in developing economies.

Thus, this article contributes to the public policy discussions concerning energy burdens and equity under household renewable energy transitions by ensuring that the voice of the poor is heard in energy decision-making process as a basic right for all. The following were the guiding research questions for this study:

1) Which households face energy insecurity in Malawi?
2) To what extent does energy insecurity incidence affect household welfare?
3) What are some of the policy lessons drawn from the research study?

These research questions were explored by paying particular attention to differences in locations (urban versus rural households) and other socio-economic characteristics to highlight the disproportionate burdens borne by vulnerable societies when meeting energy needs in their homes. The results confirm and reveal that energy insecurity heavily affected the welfare of households more especially on the education consumption with slightly large magnitude compared to the food consumption outcome. Understanding welfare effects of energy insecurity at household level in a developing country context, particularly from an energy burden perspective, is critical so that public policy design is fully informed in the Global South.

2. Materials and Methods

2.1 Data source and description

This study utilized secondary data from Malawi Integrated Household Survey (IHS4) 2016-2017. The survey was conducted by the National Statistical Office (NSO) in Malawi in collaboration with the World Bank. The datasets are publicly available and published by the World Bank as part of its Living Standards Measurement Study (LSMS) programme (NSO, 2018). The survey covers a nationally representative sample designed to provide information on the various aspects of household welfare in Malawi. The survey collected information from a sample comprising of 12,447 households but after data cleaning, this study only used 12,439 households that had all key variables for analysis. The sample was statistically designed to be representative at both national and district as well as urban and rural levels, enabling the provision of reliable estimates for these levels. The sampling involves a stratified two-stage sample design. The primary sampling units (PSUs) selected at the first stage are the census enumeration areas (EAs) as defined in the 2008 Malawi Population and Housing Census.The EAs have an average of about 235 households each. A total of 768 EAs are selected across the country.

Table 1
Literature reviewed for the study

Scholar name	Theme	Geographical context & period of analysis	Method /Approach	Energy burden problem tackled
Khandker *et al.* (2012)	Energy poverty	Cross sectional data from a comprehensive 2005 household survey from rural & Urban areas in India	Employed a demand-based approach to defining energy poverty	Focused on correlation of energy poverty and income poverty
Mirza Bilal and Szirmai (2010)	Energy poverty	Used energy poverty survey data of 2009 in Pakistan	Constructed a composite index to measure degree of energy poverty	Analyzed characteristics and consequences of different energy mixes between the rich and the poor
Foster *et al.* (2000)	Energy poverty	Used 1998/99 income expenditure survey data in Guatemala, Latin America	Employed poverty measurement techniques such as poverty head count, FGT	Used affordability indicators such as average fuel costs to measure energy poverty
Maxim *et al.*(2016); Pye *et al.* (2015)	Energy poverty	Used data from Eurostat on different proxy variables (i.e tenure status, income, well-being & material deprivation) in the year 2016	Proposed a compound energy poverty indicator (CEPI) as a standardized measure	Assessed energy poverty across all 28 EU member states
Barnes *et al.* (2010)	Energy poverty	Based on cross section data from a 2004 survey of some 2300 households in rural Bangladesh	Used instrumental variable regression to estimate welfare impacts of household energy use	Reviewed energy poverty approaches and examined role of modern energy in poverty alleviation
Moore (2012)	Energy poverty /fuel poverty	An exposition of fuel poverty definitions based on common European measure especially taking UK as a case study	Expressed fuel costs as a percentage of income and also used budget standard approach matter	Outline fuel poverty definition & argues based on budget standard approach to categorize vulnerable households
Nussbaumer *et al.* (2012)	Energy poverty	Used DHS data of 1997-2003; 2004-2009 from	Proposed a multidimensional energy poverty index	Examined incidence and intensity of energy poverty using 6 indicators (modern cooking, indoor pollution, electricity access etc.)
Thomson *et al.* (2017)	Energy poverty	Utilized pan-European datasets to do a comparative study of energy poverty across the EU	Presented statistical options for monitoring energy poverty	An exposition energy poverty measurement approaches via of vulnerability thinking
Phoumin (2019b)	Energy poverty	Used 2015 Cambodia socio economic survey dataset	Employed two stage least square	Examined impacts of energy poverty on health, education and earnings opportunities of household
Culver (2017)	Energy poverty	A 2017 critical review paper on different metrics of energy poverty	Highlighted both binary and composite metrics of energy poverty	Reviewed different metrics of energy poverty
Pachauri & Spreng (2004)	Energy access/ Energy poverty	An Indian study on energy use & energy access in relation to poverty	Employed energy use-access matrix by combining two approaches	Measured energy use & energy access in relation to poverty
Barnes *et al.* 2010	Energy access	A review on modern energy services for the poor especially World Bank portfolio projects approved from 2000 to 2008 financial year	Defined energy access as relating to both physical proximity to energy infrastructure & to policies & frameworks supporting transition to better, reliable & more efficient use of electricity & modern fuels	Compiled an up to date database on energy access related assistance & patterns of energy access related assistance
Elnakat *et al.* (2016)	Energy access	Utilized socioeconomic and demographic data at Zip code level in San Antonio service area for a period of 48 months (2009-2014)	Tested statistical significance of relationships between variables such as income, gender, occupancy, total energy, per home energy, population and others	Investigated influence of socioeconomic & demographics on residential energy utilization patterns at ZIP code level
Groh *et al.* (2016)	Energy access	A 2016 case study of Bangladesh which utilized household survey data	Compared binary indicators of energy access compared to the multi-tier framework	Evaluated the World Bank's multi-tier framework to measure electricity access
UNDP (2017)	Energy access	Utilizes country datasets and statistics of different countries to set targets on energy access indicators	Presents targets measures of energy access indicators	Highlights energy access in form of sustainable development goal 7
Colton (2011)	Energy burden	Used 3-year (2007-2009) average American community survey data published by U.S. Census Bureau	Calculated the affordability gap based on income and household energy bills in 5 primary areas (tenancy status, housing unit size, heating & cooling degree days, household size, heating fuel mix, energy use intensities	Defined home energy affordability gap in form of a bill, and a bill was considered "affordable" if it did not exceed six percent (6%) of annual household income
Cook & Shah (2018a)	Energy burden	A 2018 Feasibility study for Colorado residents to reduce energy burden with solar in North America	Evaluated low income energy burden by using housing and fuel type & Photovoltaics technical & market potential	Analyzed energy burden and Photovoltaics potential of
Drehobl and Ross (2016)	Energy burden	Used US census bureau 2011 and 2013 American housing survey data	Calculated energy burden values for 48 of the largest US cities and specific households within each city	Provided a snapshot of energy burdens in cities across the USA.
Ross *et al.* (2016)	Energy burden	Used 2016 rural household energy costs data	Analysed rural energy burdens-the percentage of household income spent on energy bills	Examined residential energy affordability in rural and small-town America and identified energy efficiency as a strategy for reducing energy burdens
Berry *et al.* (2018)	Energy insecurity	Used U.S Energy Information administration, 2015 residential energy consumption survey dataset	Explored the characteristics of energy insecure households by capturing occurrence, severity and frequency of energy insecure events lasting anywhere from few weeks to 1 year	Presented a snapshot of energy insecurity situation of US households
Ayoo (2020)	Energy insecurity	Used global statistics on production and consumption of oil from 1980 to 2017	Employed some indicators to assess changes in energy security such as promotion of energy efficiency, modernizing the grid to enable integration of the renewables such as solar	Examined multidimensional nature of energy security
Hernandez *et al.* (2016); Hernandez *et al.* (2014)	Energy insecurity	Used 2011 American community survey data	Employed multivariate statistical analysis using multinomial logistic regression	Demonstrated housing hardship and energy insecurity among the native born and immigrant low income families with children
Phoumin (2019a)	Energy insecurity	Used 2015 Cambodia socio economic survey dataset	Used multiple regression analysis	Analysed the impact of Energy insecurity on household welfare in Cambodia.

In each district, a minimum of 24 EAs are interviewed while in each EA a total of 16 households are interviewed. Dependent and Independent variables: The key dependent variables of interest were food consumption and education expenditure variables as "proxy" for household welfare. The food consumption was measured as log annual household food consumption whilst education outcome was measured as log annual household education expenditure to reduce the effects of outliers that can pose heteroskedasticity problem. NSO report provides detailed information on calculation of the consumption variables to get the annual total household expenditures (NSO, 2018).The key independent variable of interest was energy insecurity. This was constructed from the probabilities that were highlighted under the empirical model framework in the next section. The selection of the independent variables that affect welfare and their inclusion in the regression analysis was informed based on the previous studies (Nguyen & Nguyen, 2019; Phoumin, 2019; Hernandez *et al.,* 2016; Castro-Sitiriche & Ozik, 2014).

2.2 Empirical model

Statistically and economically, a Cobb-Douglas type economic welfare function (Fang, 2011) was estimated in this paper and the empirics date back to the economic theoretic works of Cobb and Douglas in 1928 and later Handsaker and Douglas plus Williams (William, 1945; Handsaker & Douglas, 1937; Cobb &m Douglas, 1928). Therefore, to measure influence of energy insecurity on household welfare outcomes, the study employed multiple regression analysis which is very sound and appropriate whenever the dependent variables are all continuous variables (Mango *et al.,*2018; Lopez-Espin *et al.,* 2012). Following Phoumin (2019) and Ross *et al.* (2018), to get a thorough understanding on how much households are energy-burdened, the hypothesis of assessing how household energy insecurity incidence affects household welfare (food consumption and education consumption outcomes) is formulated as follows:

$$\mathrm{P}(E_i = 1) = \mathrm{Q}(E_i = SE > 10\%) \; if\ household\ is\ not\ energy\ secure;$$

$$\mathrm{P}(E_i = 0) \quad if\ otherwise \tag{1}$$

Where SE is the share of energy expenditure to the total household expenditure, Q(.) is an indicator function that may take values 1 if the expression in the brackets holds and zero otherwise. It depicts that when Q(.) takes the value of 1, then that household is energy insecure. Therefore, mathematically, household incidence of energy insecurity (EI) is formulated as follows:

$$EI_i = \frac{1}{N}\sum_{i=1}^{n}[\,\mathrm{Q}(E_i = SE > 10\%)] \tag{2}$$

Now to link the household energy insecurity incidence to household welfare (food consumption and education expenditure outcomes), two structural equations were formulated as follows:

$$W_i = \phi_0 + \phi_1 EI_i + \phi_i X_i + u_i \tag{3}$$

Table 2
Regression diagnostic test on multi-collinearity

Variable	VIF	1/VIF
Marital status	2.46	0.4064
Log per capita household annual consumption	2.30	0.4351
Gender of Household head	2.23	0.4493
Grid electricity access	2.02	0.4943
Urban location	2.00	0.4992
Tenancy	1.99	0.5031
Main source for drinking water	1.93	0.5171
Household size	1.68	0.5963
Owner occupant	1.68	0.5968
Plot ownership	1.54	0.6482
Household head with some education	1.28	0.7823
Household energy insecurity status	1.26	0.7958
Livestock ownership	1.17	0.8528
Age of household head	1.13	0.8844
Mean VIF	1.76	

Source: Authors' estimation from Malawi IHS4 (2016/17)

$$W_i = \gamma_0 + \gamma_1 SE_i + \gamma_i X_i + \varepsilon_i \tag{4}$$

Where W_i is household welfare which is the dependent variable depicting food consumption and education consumption outcomes in both equations. The first structural equation (3) captures household energy insecurity incidence (EI_i) as part of the regressors to assess the direct effect on household welfare. In the second structural equation (4), the share of the energy expenditure (SE_i) was used to assess the magnitude of the effect of the energy insecurity incidence. Finally, X_i is a vector of socio-economic factors (such as education , age , household size and others) that also affect household welfare whilst;u_i and ε_i are error terms and are normally distributed which implies $u_i\ or \varepsilon_i \backsim$ N (0,1) and ϕ, γ were parameters that were estimated using ordinary least squares (OLS) regression models because the two dependent variables were continuous in this case. Again, to address the heteroscedasticity problem the two dependent variables were transformed into natural logarithm form.

The multiple regression was used to test the study's existing hypotheses. As such, multi-collinearity test was conducted and results showed that the Variance Inflation Factors (VIF) for the covariates were within the allowable limit of below 10 (refer Table 2) and this implies that there was no multi-collinearity problem with the data (Zou & Luo, 2019; Phoumin, 2019). Additionally, the robustness standard errors correction techniques such as using "the option robust" in STATA 14 statistical software was used to reduce inflation of the estimated coefficients more and T-statistics.

3. Results and Discussion

3.1 What are characteristics of households that are facing EI?

Recalling the definition of energy insecurity in the methodology section, this study found that 42.58% of the households were energy insecure. Differences in households faced with energy insecurity were defined by several factors: (a) energy choices and electricity status, (b) geographic variables (regional or district location) (c) demographic variables and (d) housing tenure, dwelling status and asset variables. Firstly, the energy insecure households are differentiated by energy sources for lighting and cooking (Table 3). Table 3 compares the means of the lighting and cooking fuel choices for the sample households based on their energy insecurity status. The significant P-values show that there were some differences between the two groups. The main household energy sources for lighting that were reported were gas, grid electricity, kerosene, candles, torches, fuel wood and other fuels such as grass as indicated in Table 3. On the other hand, the main household energy sources for cooking were gas, electricity, kerosene, charcoal, fuel wood and other fuels such as crop residues and saw dust. The significant P-values showed that the energy use patterns of the two groups were unbalanced with respect to accessibility of modern energy services infrastructure. The result showed that the energy insecure tend to use kerosene, fuel wood as their lighting fuels more than the energy secure. Regarding cooking fuels, the energy insecure tend to use fuel wood more compared to the energy secure in relative terms.

Regarding the grid electricity access and frequency of blackouts, tree maps visualization techniques were employed using Microsoft Excel software as a representation of hierarchical information to see the differences between the two groups in the year 2016/17 (Aberman *et al.,* 2018; Long *et al.,* 2017). The differences are shown graphically in Fig 2 for grid electricity access for the whole sample and in Fig 3 frequency of blackouts for the sub-sample of the grid connected households. These findings resonate with Jessel *et al.* (2019) who described energy insecurity as either a long-term issue that can arise from a consistent inability to access adequate energy to meet household needs or a short-term issue that tends to arise from infrastructural , maintenance, environmental or other external sources that disrupt access to energy sources.

Table 3
Mean comparison for lighting and cooking fuel variables

Variable	Difference in mean	
	(energy -secure)-(energy-insecure)	p- value of diff.
Lighting fuel choices		
Gas& grid electricity (1 =yes)	0.063	0.000
Kerosene (1=yes)	-0.029	0.000
Fuel wood (1=yes)	-0.014	0.000
Torches (1 = yes)	0.002	0.766
Others i.e grass (1 = yes)	-0.022	0.000
Cooking fuel choices		
Gas& grid electricity (1= yes)	0.027	0.000
Kerosene & charcoal (1=yes)	0 .058	0.000
Fuel wood (1=yes)	-0.102	0.000
Other fuel i.e. dung (1=yes)	0.017	0.000
Observations	12,439	

However, the IHS4 dataset did not allow to assess other purposes for energy utilization and also multiple fuel use which is termed as "fuel stacking" because the respondents were only asked to mention their main fuel sources for lighting and cooking in the homes. "Fuel stacking or energy transition" asserts that utilization of both clean and unclean energy fuel sources still occurs regardless of household high-income levels for various reasons (Heltberg, 2005; Masera *et al.,* 2000). For this study, it was not possible to test the fuel stacking hypothesis since the IHS4 dataset did not capture information regarding primary and secondary fuels for lighting and cooking purpose except only for those that were connected to the national grid. Reasons for multiple fuel use by households in developing countries have been attributed not only to economic factors but other factors as well that are deeply connected to culture, the social make-up or indeed just to increase security of supply based on household needs (Mekonnen & Kohlin, 2009; Pachauri & Spreng, 2004).

As a result, binscatter plots were used to assess only the energy ladder hypothesis for the sampled households based on their energy security status (Martey, 2019; Cattaneo, 2019). The energy ladder hypothesis stipulates that households with low income level are likely to consume traditional fuels such as crop residues at the bottom of the ladder that are considered as "dirty" but as the income increases, the households are likely to move up the ladder by switching to transitional fuels such as charcoal or kerosene and finally to modern fuels such as gas and electricity as their income increases furthermore (Toole, 2015). Fig 4 and Fig 5 indicate the binscatter plots to show the relationship between the lighting and cooking fuel choices of the sampled households based on the energy insecurity status respectively. Firstly, the results from Fig.4 show that both the energy-secure and energy-insecure households seemed to have same relationship for all lighting fuels and household expenditure quintiles with exception of choice of other fuels such as grass. The energy-secure had an inverse relationship over the choice of other fuels whilst the energy-insecure showed a positive relationship with this type of fuel source.

Secondly, with regard to cooking fuels, Fig.5 showed that the energy secure were more likely to use more of modern fuels (gas, electricity) relative to the energy insecure as the income kept on rising. However, both the energy-secure and energy-insecure had similar positive relationship with transitional fuels (kerosene, charcoal) as their income increased. Lastly, the energy secure were less likely to use traditional fuels such as fuel wood or crop residues as their income increased. It was interesting to note that the energy insecure were also less likely to use fuel wood when their income rose. However, they seemed to have a constant relationship with use of other fuels such as crop residues and grass as their income rises. These findings resonate well with both current and old literature which show that energy insecurity is a complex issue because it intersects with other hardships such as food insecurity (Banash *et al.,* 2013), water (Webber, 2016) and housing insecurity (Hernandez, 2013) coupled with other social burdens (Cook *et al.,* 2008). Apart from energy choices and services other differences were observed in demographic variables (Table 4), geographical variables (Table 5), and housing, dwelling status and asset variables (Table 6).

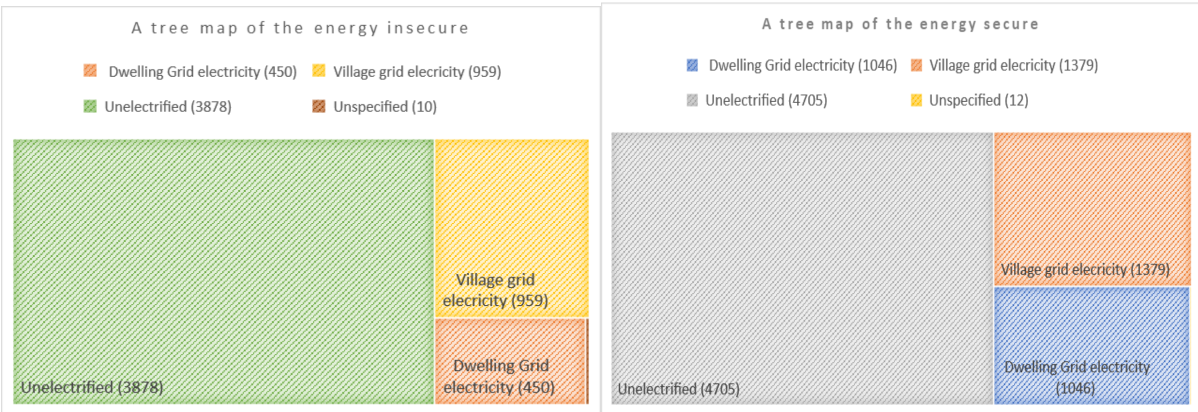

Fig. 2 A graphical representation of grid electricity connection, by energy insecurity status. (Source: Authors' estimates based on the data from IHS4 data, NSO, 2018)

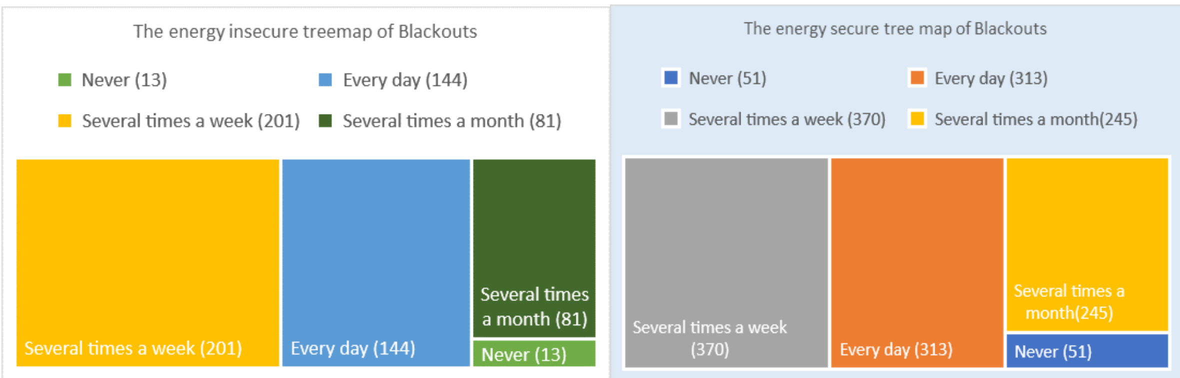

Fig. 3 A graphical representation of blackouts patterns, by energy insecurity status. (Source: Authors' estimates based on the data from IHS4 data, NSO, 2018)

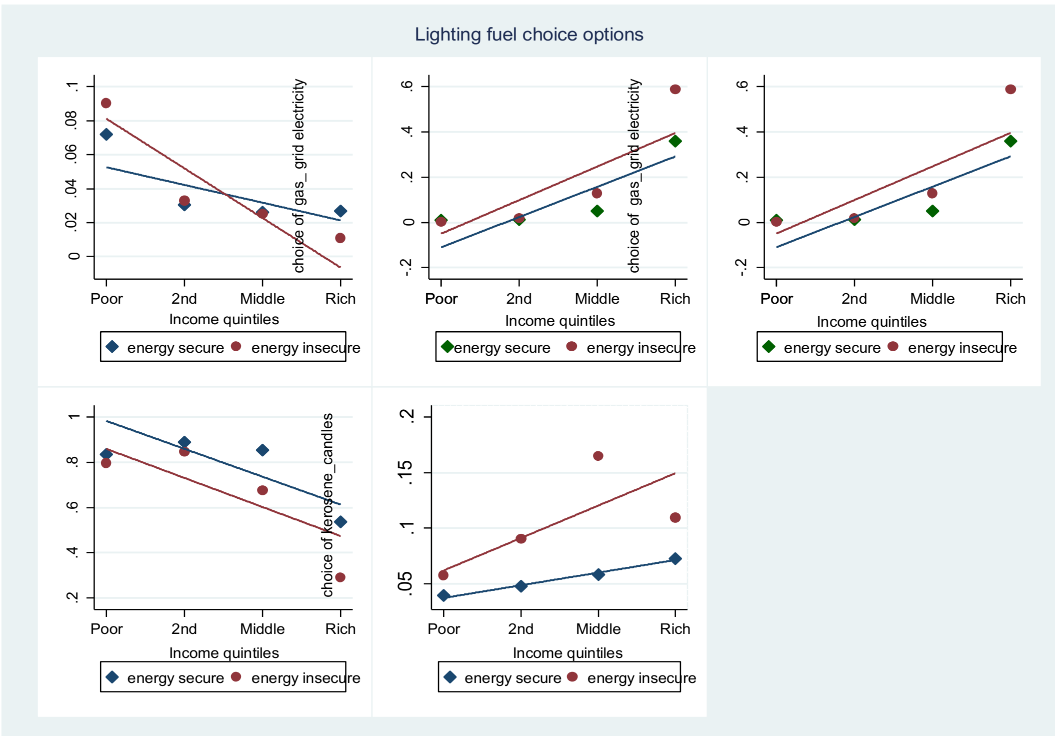

Fig.4 Lighting energy choice and Income by energy insecurity status

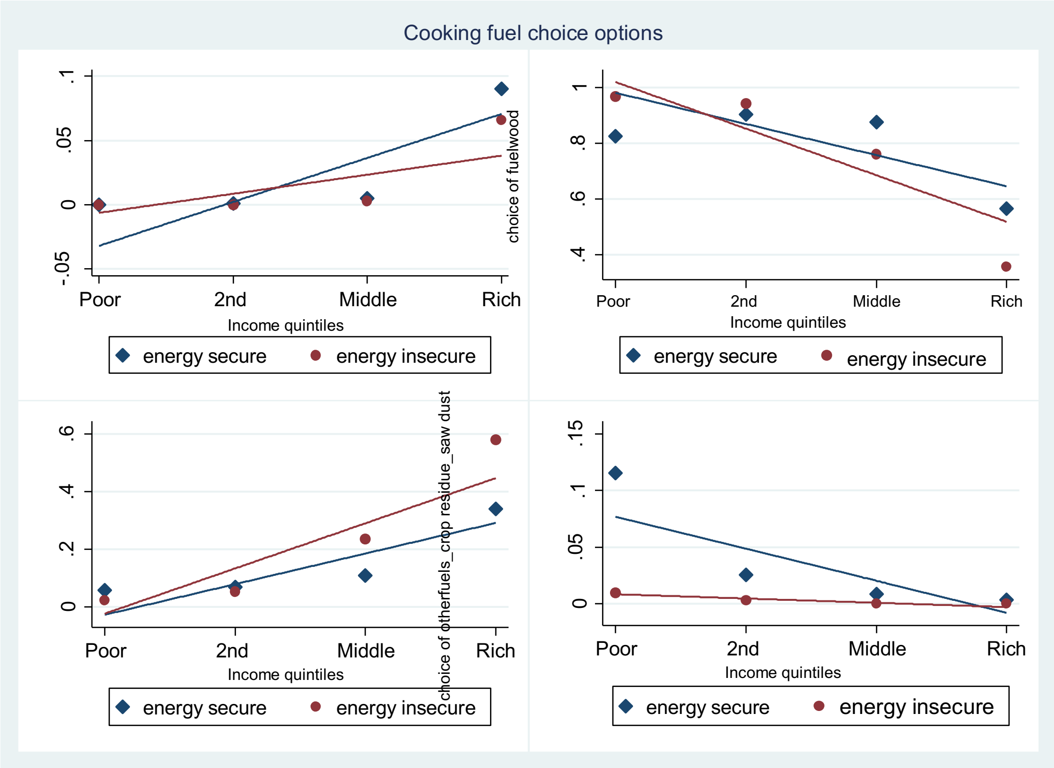

Fig.5 Cooking energy choice and Income by energy insecurity status

Table 4
Mean comparison for demographic variables

Variable	Difference in mean	
	(energy secure)- (energy insecure)	p-value of diff.
Gender (1=male)	0.113	0.000
Marital status of Household head (1 =yes)	0 .142	0.000
Age (years)	-0.886	0.000
Household head with no education (1=yes)	-0.073	0.000
Household head with primary education (1 = yes)	0 .018	0.000
Household head with secondary education (1 = yes	0 .038	0.000
Household head with tertiary education (1 = yes)	0.016	0.000
Household size (number)	0.994	0.000
Poverty status (1 = yes)	-0.202	0.000
Children (number of those below 6 years)	0 .112	0.000
Elderly (number of those above 60 years)	-0.058	0.000
Total annual household expenditure per capita	570122.4	0.000
Plot ownership (1=yes)	-0.039	0.000
Livestock ownership (1=yes)	0.145	0.000
Share of energy expenditure	-9.290	0.000
Observations	12,439	

Table 4 presents differences in means of the demographic variables of the sampled households based on energy insecurity status. The result shows that the groups were not balanced following the P-value calculated using the Welch t-tests. In comparison to energy secure counterparts, the energy insecure on average were likely to be those advanced in age and less likely to be males (Hernandez *et al.*, 2016), elderly especially those above 60 years of age (Farbotko and Waitt, 2011), headed by those without formal education (Gonzalez-Eguino, 2015; Cook *et al.*, 2008), more likely to be those who were poor in monetary terms (Hernandez, 2016), those who at least own a plot of land and finally those incurring a large share of energy expenses. Nevertheless, geographical and regional differences also play a big role. For instance, largest proportion of energy insecure households were found in the rural South (44%) where Chiradzulo and Mangochi districts were mostly affected seconded by rural centre (33%) where Lilongwe and Dedza districts were heavily affected as depicted in a Fig.6 and Fig.7.

Fig.7 which is a pareto chart provides a graphical display of Pareto which stipulates that when observing events, it is a phenomenon that 80% of events are due to 20% of the possible causes (Thiede *et al.,* 2012). The Pareto Principle in which ~20% of the problem referred to "vital few" in a population account for ~ 80% of "useful many trivial" (the rest of the districts). Hence, Fig.7 displays the frequencies of energy insecurity incidence in a descending order of observations, with bars depicting frequency in a given district whilst the line represents percentage of cumulative frequency (Jankowski *et al.,* 2013).

The Pareto chart presents the findings from highest to lowest frequency for energy insecurity occurrences in this context. This type of analysis assists in indicating the few issues that cover the majority of the cases and the connected line represents the cumulative percentage line for the issue at hand. Pareto charts are used to choose the starting point for problem solving, monitoring changes, or identifying the basic cause of problem (Bednar *et al.*, 2017).

Finally, Table 5 also reports the mean comparison for geographical variables of the sampled households based on their energy insecurity status. The results from welch t-tests revealed that there were indeed significant differences between the two groups attributed to geographical reasons or location. The Energy insecure were less likely to be found in urban areas and rural North. These results resonate with those study findings from Global North whereby spatial inequality and disparity in energy insecurity may exist between urban and rural areas due to limited access to modern energy sources such as gas or other electricity services that may easily be found in the urban communities (Jesse *et al.,* 2019; Bednar *et al.*, 2017).

Finally, Table 6 shows that there were also significant differences regarding housing, dwelling status and asset ownership amongst the sampled households after comparing the means using Welch t-tests based on their energy insecurity status because wealth inequality is becoming an issue of concern (Jesse *et al.,* 2019).

Table 5
Means Comparisons for geographical variables

Variable	Difference in mean	
	(energy secure)-(energy insecure)	p-value of diff.
Urban (1=yes)	0.067	0.000
Rural North (1=yes)	0.122	0.000
Rural Central (1=yes)	-0.092	0.000
Rural South (1=yes)	-0.097	0.000
Observations	12,439	

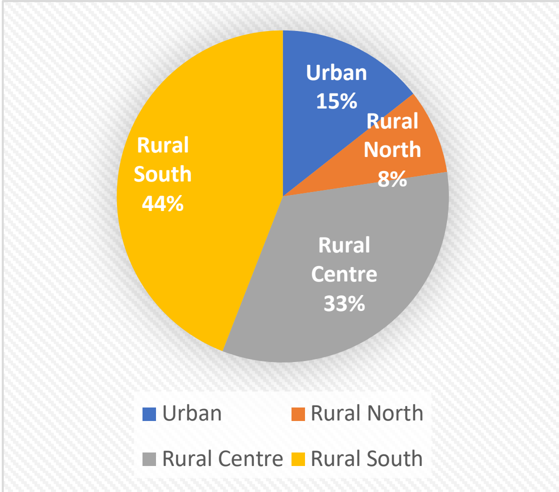

Fig.6 Regional distribution of energy insecurity incidence (%)

The Energy-insecure were more likely to dwell in houses built with traditional materials, more likely to live in houses with grass thatched roofs and smoothed mud floor but less likely to be found in houses with burnt brick outer walls.

In terms of dwelling status, the energy insecure were less likely to be tenants but rather they were more likely to occupy houses in which they were either freely authorized to occupy or they occupy freely but not authorized to do so and not necessary being the actual owners. In addition, in terms of selected asset ownership, the energy insecure were less likely to own electrical gadgets such as refrigerator, TV, and fan. These results show that energy insecurity is influenced by housing tenure because renting, owning or free occupancy with or without authorization may result into unique problems that can escalate the energy insecurity challenge (Jesse *et al.*, 2019; Martey, 2019). This depicts that the energy insecure might have more freedom to utilize any available energy sources with more free space without facing landlord restrictions as it is usually the case of those living in the rented homes (Bisu *et al.,* 2016). Literature shows that poor tenants may have problems with house rents and may not afford to do efficiency upgrades set by landlords (Bird & Hernandez, 2012). For Malawian case (or in the case of Malawi) , this is different because, the energy insecure were found to occupy dwellings in which they were freely authorized or they occupied freely without authorization which meant there may be other factors as well. The energy-insecure were also less likely to own even solar panels which are renewable and alternative clean energy source. This finding is critical since adoption of solar home systems was attributed to high income levels that would allow household transition to solar energy use to take place (Lay *et al.,* 2013).The results resonate with the findings of Middlemiss and Gillard (2015) who identified six challenges attributed to energy vulnerability namely; energy costs and supply issues, dwelling quality, household income stability, tenancy reasons, ill health and social relations.

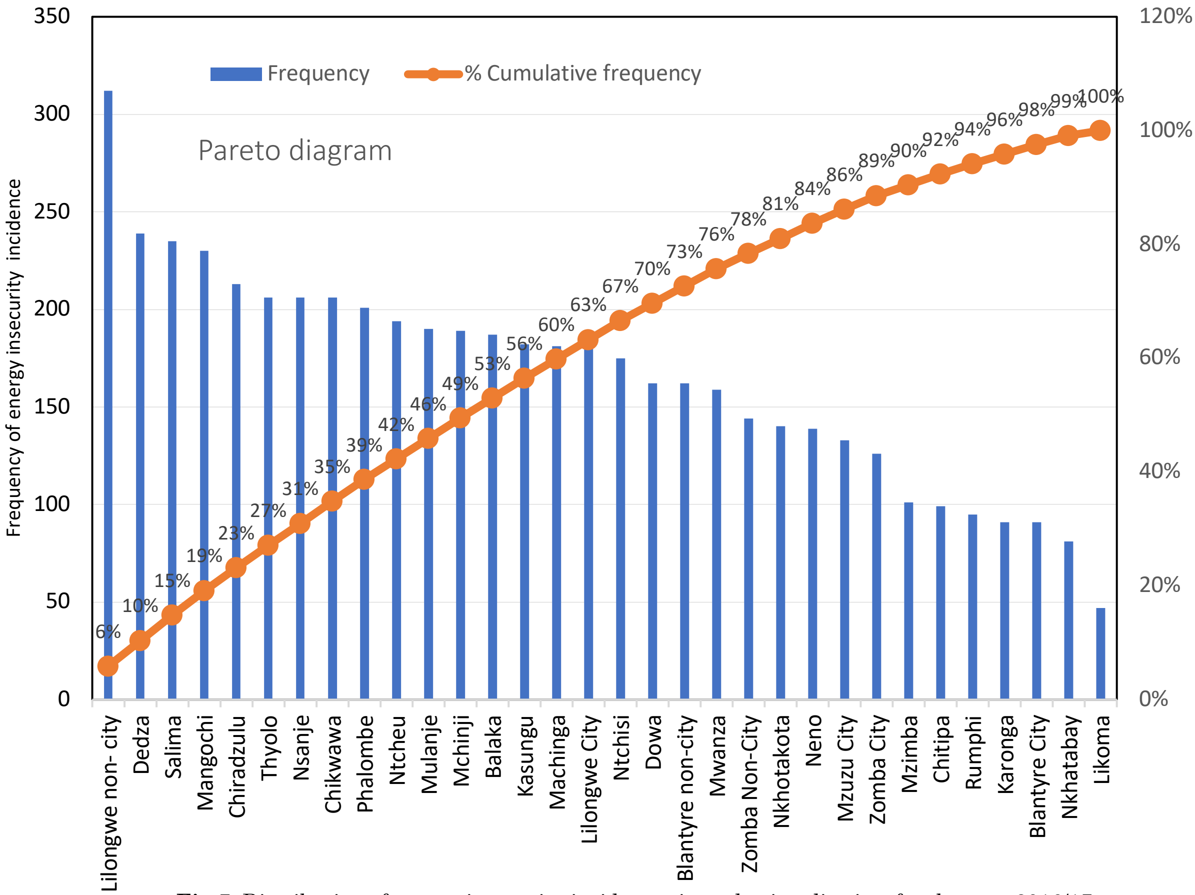

Fig.7. Distribution of energy insecurity incidences in malawian districts for the year 2016/17

Table 6
Means Comparisons for housing, dwelling status, and asset variables

Variable	Difference in mean	
	(energysecure)- (energyinsecure)	p-value of diff.
Dwelling status as owner occupant (1=yes)	-0.012	0.111
Dwelling status as free but authorized or free not authorized (1=yes)	-0.039	0.000
Dwelling status as tenant occupant (1=yes)	0.038	0.000
Traditional latrine with roof (1=yes)	0.048	0.000
Number of sleeping rooms	0.425	0.000
Routine home maintenance	12363.56	0.000
Expenditure on actual rents	4491.88	0.000
Dwelling with traditional construction material (1 = yes)	-0.163	0.000
Grass thatched roof (1 = yes)	-0.166	0.000
Smoothed mud floor (1 = yes)	-0.135	0.000
Burnt brick outer wall (1=yes)	0.143	0.000
Own TV (1=yes)	0.089	0.000
Own Satellite dish (1=yes)	0.044	0.000
Own electric or gas stove (1=yes)	0.042	0.000
Own iron for pressing clothes (1=yes)	0.115	0.000
Own refrigerator (1=yes)	0.048	0.000
Own Solar panel (1=yes)	0.045	0.000
Own fan (1=yes)	0.038	0.000
Own Satellite dish (1=yes)	0.044	0.000
Observations	12,439	

3.2 To what extent does energy insecurity incidence affect household welfare?

The main hypothesis for this paper was to assess how household energy insecurity impacts household welfare (food and education consumption). The analytical technique involved estimating multiple regression models (Model 1 and Model 2). The results from these models are presented in Tables 7 and 8. The regression results from Model 1 in Table 7 showed that household energy insecurity decreased household food consumption by 17% in reference to those that were energy secure. Similarly, a closer look at the household education outcome (Table 8) indicates that those that were energy insecure at household level experienced a large decrease of approximately 33.4% in its education consumption compared to the energy secure households. This finding shows that energy security plays a key role towards improvement of household welfare in general as it largely affects household consumption of the basic necessities.

In order to get a thorough understanding in terms of magnitude of the effect of energy insecurity on household welfare the study further looked at proportion of energy expenditure to the total expenditure. The regression results from model 2 (Table 7) indicate that energy-insecure households were likely to reduce expenses on food consumption approximately by 2.3 % for each 1% unit increase in energy expenditure proportional to total household expenditure. As for the education outcome, Table 8 shows that energy-insecure households were likely to reduce education expenditure by 3.6 % for each 1% unit increase in energy expenditure proportional to total household expenditure. This implied that food and education expenses were likely to be affected by each proportion set aside for energy expenditure at household level.

Regarding other socio-economic characteristics that had displayed large effects on the household welfare. Considering the food consumption, household income level "proxied' by log per capita consumption had positive influence on food consumption by 81%. Others that positively affected food consumption were marital status (23% increase); plot ownership (4 % increase), livestock ownership (2% increase) and owner occupants (2% increase). These findings suggest the need to explore installation of biogas plants as renewable energy source especially to those who own livestock and plots following an Ethiopian case study that showed economic benefit in form of money savings from fuel expenses and income generation through selling slurry that replace chemical fertilizer (Alemayehu, 2015). On the other hand, some of the factors that had negative influence on food consumption were drinking water access (5% decrease); education level of household head (4% decrease).

As for education outcome, some of the factors that positively affected it were grid electricity access (37 % increase), log per capita consumption (58% increase), urban location (62% increase), plot ownership (36.6% increase), livestock ownership (42.6% increase). Those factors that showed negative influence on education consumption included: gender of household and marital status of household head (65.8% decrease).

Table 7
Regression coefficient estimates of log of household food consumption

Covariate	Model 1*	Model 2†
Urban location	-0.007 (0.011)	-0.001 (0.011)
Education of household head	-0.038 (0.010)***	-0.039 (0.009)***
Main source of drinking water	-0.048 (0.012)***	-0.050 (0.012)***
Gender of Household head	-0.152 (0.012)***	-0.141 (0.011)***
Age of Household head	-0.001 (0.000)***	-0.001 (0.000)***
Household size	0.233 (0.003)***	0.219 (0.003)***
Household Energy insecurity status	-0.173 (0.007)***	excluded
Share of energy expenditure	Excluded	-0.023 (0.001)***
Marital status of Household head	0.229 (0.012)***	0.209 (0.011)***
Tenancy	0.000 (0.013)	-0.006 (0.013)
Plot ownership	0.041 (0.008)***	0.041 (0.008)***
Livestock ownership	0.019 (0.006)***	0.013 (0.006)**
Owner occupant	0.018 (0.008)**	0.017 (0.008)**
Log per capita consumption	0.811 (0.014)***	0.762 (0.014)***
Grid electricity access	-0.034 (0.013)**	-0.008 (0.013)
Constant	2.105 (0.172)***	2.905 (0.178)***

Measure of goodness of fit. Number of obs=12,438; F (14, 12423) =1818.66; Prob > F=0.0000; R-squared=0.7822 Root MSE=0.3196.
Note: *** (1% level of statistical significance); **(5% level of statistical significance); * (10% level of statistical significance)

* Multiple regression model (Model 1) used Robust Standard Error Correction and excluded 'share of energy expenditure to total expenditure as a regressor.
† Multiple regression model (Model 2) used Robust Standard Error Correction and excluded 'energy insecurity status' as a regressor.

Table 8
Regression coefficient estimates of log of household education expenditure

Covariate	Model 1*	Model 2†
Urban location	0.625 (0.112)***	0.632 (0.112)***
Education of household head	0.369 (0.102)***	0.371 (0.102)***
Main source of drinking water	0.154 (0.129)	0.148 (0.129)
Gender of Household head	-1.076 (0.102)***	-1.060 (0.103)***
Age of Household head	0.025 (0.002)***	0.026 (0.002)***
Household size	1.492 (0.022)***	1.476 (0.023)***
Household Energy insecurity status	-0.334 (0.068)***	excluded
Share of energy expenditure	excluded	-0.036 (0.005)***
Marital status of Household head	-0.658 (0.109)***	-0.686 (0.109)***
Tenancy	0.386 (0.140)***	0.377 (0.139)***
Plot ownership	0.366 (0.091) ***	0.364 (0.091)***
Livestock ownership	0.426 (0.065)***	0.421 (0.065)***
Owner occupant	0.050 (0.088)	0.049 (0.088)
Log percapita consumption	0.581 (0.074)***	0.523 (0.076)***
Grid electricity access	0.994 (0.134)***	1.026 (0.135)***
Constant	-8.009 (0.935)***	-7.013 (0.978)***

Measure of goodness of fit. Number of obs=12,438; F (14, 12423) = 646.47; Prob > F =0.0000; R-squared=0.4497 Root MSE=3.3083. Note: *** (1% level of statistical significance); **(5% level of statistical significance); * (10% level of statistical significance

3.3 Policy recommendations

The policy implications from this study are threefold. Firstly, the government together with electricity companies to upscale and increase beneficiary targeting of the Malawi rural electrification programme to increase electricity access, taking into consideration geographical and resource factors. In addition, the government needs to engage in public information and demonstration campaigns to raise consumer awareness on availability of affordable, modern and sustainable energy products.

Secondly, the government of Malawi needs to encourage the existing electricity companies to quickly adopt and implement vibrant demand side management program that will aim at ensuring not only energy efficiency but also energy savings through popularization of solar for lighting, LPG and certified improved cook stoves so that consumers are stress-free from bill payments and overburdened utility systems. The option for solar can be achieved through “Pay as You Go” scheme. Suffice to say that majority of Malawian households rely on biomass fuel and are skeptical to use LPG and certified cook stoves due to safety concerns and low technical knowledge (Practical Action, 2017; Maganga *et al.,* 2015).

Finally, there is need to introduce and pilot a special energy security scheme that can target the elderly and female headed households for both the rural and urban poor so that they are cushioned especially now with the coming of the Corona virus/COVID-19 pandemic.

4. Conclusion

The objectives of this research study were to characterize the households which face energy insecurity and also analyze the effect of energy insecurity on household welfare (food and education consumption outcomes) in Malawi. Using nationally representative sample dataset and from Global South context under a micro-economic perspective, this study revealed that the energy-insecure are a heterogenous group who differ from their energy-secure counterparts in terms of demographics; socio-economic status; household energy use patterns; housing and dwelling status; and geographical location. Additional results from econometric analysis showed that energy insecurity decreased household food consumption and education expenditures.

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* Multiple regression model (Model 1) used Robust Standard Error Correction and excluded ‘share of energy expenditure to total expenditure as a regressor.
† Multiple regression model (Model 2) used Robust Standard Error Correction and excluded ‘energy insecurity status’ as a regressor.

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