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Multidimensional Measure of Household Energy Poverty and its Determinants in Ethiopia

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Preface

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Multidimensional Measure of Household Energy Poverty and its Determinants in Ethiopia[1]

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Abstract

Access to and affordability of energy is crucial for the well-being of society. Life without energy is unthinkable. It is an important ingredient for attaining the general good quality of life. The objective of this study is to analyze the extent and determinants of energy poverty using the Ethiopian Socioeconomic Survey of 2011 and 2014 which is part of the World Bank survey on living standards. The analysis focuses on multidimensional measures of energy poverty using four dimensions and five variables for rural and small towns in Ethiopia. The determinants of multidimensional energy poverty and their effects are also examined using the static random effect logit model. The results show that the extent of energy poverty in rural and small towns in Ethiopia is very severe. About 74 per cent and 73 per cent of the respondents were found to be multi-dimensionally energy poor in 2011 and 2014 respectively. Further, the results also show that a larger family size, living in a rural area and male headed households significantly increase the probability of a household being multi-dimensionally energy poor while the age of the household head, the number of rooms occupied by the household and total household expenditure significantly reduce the probability of households falling into poverty. The study recommends that interventions for reducing energy poverty should be coupled with poverty reduction policies, promotion of rural energy and energy efficient technologies and appropriate energy source pricing mixes.

Keywords: Energy poverty, Ethiopia, multidimensional, random effect logit.

JEL classification codes: C25; D12; I32; N77; Q47.

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1. Introduction

Energy is used in cooking, lighting, production, communication, heating and cooling. It is crucial for the well-being of society. Life without energy is unthinkable. Energy is an important ingredient for attaining good education and health and good quality life in general. Access to modern energy is crucial for economic development via its contribution to improved health conditions, reducing indoor air pollution, increasing production and productivity using modern technologies and machinery, saving time, adding to further education and expansion of health facilities (Barnes et al., 2011). Lack of access (both physical and economical) to reliable energy is believed to hamper economic growth and reduce the welfare of citizens (Chakravarty and Tavoni, 2013).

Moreover, energy is central to addressing many of today's global development challenges like poverty, inequalities, health, education, digital divide, connectivity and climate change (Foster et al., 2013; Nussbaumer et al., 2012). Despite the massive contribution of energy to economic progress and the important role that it plays in the process of economic development, there are indicators that the global energy system will face various challenges that will question issues of sustainability and energy security in the future. Among the challenges are increasing risks of shortages of energy supply, especially non-renewable sources; the threat to the environment caused by fossil fuel energy production and use; and persistent energy poverty. These challenges can be remedied only through strong and coordinated government action and public support (Birol, 2007).

Access to and use of modern energy sources both physically and economically for most poor households is inconceivable. In the case of rural parts in developing countries not only economic access but physical access too is a major problem. The only dominant source of safe energy is electricity generated by using various primary energy sources but with limited physical access. Access to reliable and affordable energy as well as energy security has shown limited promising improvements for developing countries. As a result, the issue has been on the academic and policy agendas for considerable time. Even though this has been a concern for developing countries since the 1980s, the problem of energy poverty has not yet been resolved in these countries (Barnes et al., 2011; Birol, 2007; Li et al., 2014; Pereira et al., 2010).

In the context of development energy is mainly used for lighting, cooking, production and communication. Energy poverty is considered one of the most important issues related to development. It is believed to be both the cause and the manifestation of poverty. The energy poor are defined as households who cannot meet their basic energy consumption needs. Breaking the vicious circle of energy poverty, eradicating energy poverty and achieving sustainable development in developing countries will be realized only with concerted efforts of researchers, policymakers, donor organizations and state governments (Birol, 2007; OFID, 2008).

Strikingly, in recent years about 1.4 billion people in developing countries have had lack of access to electricity and about 3 billion people have relied on inefficient and polluting fires for cooking and other household needs. Most of the electricity-deprived populations are in sub-Saharan Africa and South Asia. Further, about 80 per cent per cent of those without access to electricity live in rural areas (UNDP and WHO, 2009; WEO, 2014). Ethiopia, ranked 157th on the human development index, is one of the least developed countries in the world. It has one of the lowest rates of access to modern energy services.

Its energy supply is primarily based on biomass. About 90 per cent of the primary energy source in the country is biomass while oil accounts for about 7 per cent and hydropower for 0.9 per cent. Besides, the energy use pattern in the country shows that households account for 88 per cent of total energy consumption followed by industry (4 per cent), transport (3 per cent) and services and others (5 per cent). Regardless of its high potential for production of modern energy, only about 23 per cent of the population in Ethiopia has access to electricity[2] (Dawit, 2012; WEO, 2013, 2014).

As a response to development challenges and its aspirations of having inclusive and sustainable development, Ethiopia launched an ambitious medium term development plan – the growth and transformation plan (GTP) in 2011. The country put a target of attaining middle income status by 2025 and the plan aligned its growth path with climate resilient green growth. In line with this plan, the country embarked on an expansion of modern energy sources and its energy sector is considered an important pillar for realizing green growth and accelerating development in the country (FDRE, 2011a, 2011b). However, currently the country's energy use pattern questions the sustainability and security of its energy use. Moreover, a majority of the households, especially in the rural parts, rely on traditional sources of energy. This signals persistence of energy poverty in the country.

Globally there is a lot of literature on energy (fuel) poverty (Barnes et al., 2011; Boardman, 1991; Chakravarty and Tavoni, 2013; Foster, 2000; Nussbaumer et al., 2012; Walkera et al., 2014). For sub-Saharan African countries there are a few studies available on energy poverty (Edoumiekumo et al., 2013; Tchereni et al., 2013). However, there is paucity of research on energy poverty in Ethiopia especially of studies employing a multidimensional measurement approach. A study by Bekele et al., (2015) only examines the extent and determinants of multidimensional poverty in Ethiopia's capital Addis Ababa. Thus, the present study contributes to general literature on energy poverty and provides a concrete metric for Ethiopia. Using a rich dataset of the household survey, the study analyzes the extent and determinants of energy poverty in Ethiopia. This study is expected to deepen an understanding of the causes and extent of energy poverty. It further investigates the most important attributes for multidimensional energy poverty and examines the extent of energy poverty for different groups of households in rural and small towns in Ethiopia. This is expected to indicate policy instruments for the post-2015 sustainable development strategy and will bridge the exiting knowledge gap in the causes of energy poverty and indicate the way forward for a smooth transition to a modern energy system.

This research elaborates on several aspects of energy poverty with implications for the well-being of society. These include the many dimensions of energy poverty, the implications of persistence energy poverty and poverty reduction and the association between energy poverty traps and specific household characteristics. For this a number of research questions were formulated to do an analysis:

- What is the most important dimension of energy poverty?
- What does it mean for a country like Ethiopia's persistent energy poverty?
- Do household characteristics really matter in energy poverty?

[2] https://energypedia.info/wiki/Ethiopian_Energy_situation accessed on 11/19/2013.

The rest of this study is organized as follows. Section 2 provides a brief summary of access to energy, reviews the definitions of energy poverty and presents a metric multidimensional measure. It further discusses literature summarizing empirical works on energy poverty. The data and methodology are presented in Section 3. Section 4 has a discussion of the results. The final section gives a conclusion and policy recommendations for achieving the sustainable development goals (SDGs).

2. Issues in Energy Poverty

2.1 Energy potential and access

Access to modern energy is related to the level of economic development. In particular, the electrification rate seems to parallel a country's economic status. According to WEO's (2013) report a lower electrification rates and higher numbers of people without access to electricity are more prevalent in developing countries. Globally about 1.4 billion people have no access to electricity regardless of impressive electrification rates of about 81.9 per cent with an urban electrification rate of 93.7 per cent and a rural electrification rate of only 69 per cent (Table 1).

Table 1. Electricity access in 2011-regional aggregates

Region	Population without electricity (in million)	Electrification rate (per cent)	Urban electrification rate (per cent)	Rural electrification rate (per cent)
Developing countries	1257	76.5	90.6	65.1
Africa	599.7	42.6	65.2	27.8
North Africa	1	99.4	100	98.7
Sub-Saharan Africa	598.7	31.8	55.2	18.3
Developing Asia	614.7	83.1	95	74.9
India	306.1	75.3	93.9	66.9
Rest of developing Asia	308.6	87.1	95.3	80.2
Latin America	23.8	94.8	98.5	81.1
Middle East	18.7	91	98.5	75.8
Transition economies & OECD	1.1	99.9	100	99.7
World	1258.1	81.9	93.7	69

Source: Adapted from WEO (2013).

Developing countries are home to almost entire populations without access to electricity. Nearly half of these people are in Africa where the overall electrification rate is only 42.6 per cent (urban electrification rate of 65.2 per cent and rural electrification rate of 27.8 per cent). These figures are very alarming for sub-Saharan African (SSA) countries. About 47.5 per cent of the population without access to electricity is living in SSA countries. Here the overall electrification rate is only 31.8 per cent (urban electrification rate of 55.2 per cent and rural electrification rate of 18.3 per cent). Ethiopia is among the countries with a lower electrification rate in SSA countries. Even though more than half of Ethiopia's population is geographically close to the electricity grid, about 70 million people are without access to electricity. The overall electrification rate in the country is about 23 per cent (urban electrification rate of 85 per cent and rural electrification rate of only 11 per cent). The country is performing well as compared to Africa and SSA countries' average urban electrification rates. However, it is performing poorly in rural electrification which is below the average SSA rural electrification rate (18.3 per cent). The country's per capita domestic electricity consumption is less than 100 kWh per year lower than the SSA countries' average level (317 kWh per year) and less than what a refrigerator uses per year in a developed country (Power Africa, 2015; WEO, 2013, 2014).

Even though it is underdeveloped, Ethiopia is endowed with diversified energy sources. It has huge potential of various energy sources which are underdeveloped but promisingly exploitable at different scales. So far the renewable energy potential of the country is predominantly generated from hydropower which is far below the capacity of the country. Energy potential from biomass remains dominant and is exploited in the rural parts (Table 2).

Table 2. Ethiopia's renewable energy potential

Resource	Unit	Exploitable reserve	Exploited	
			Amount	Per cent
Hydropower	MW	45,000	~2100	<5 per cent
Solar/day	kWh/m2	4 –6		<1 per cent
Wind power	GW	1350	171MW	<1 per cent
Geothermal	MW	7000	7.3 MW	<1 per cent
Wood	Million tons	1120	560	50 per cent
Agricultural waste	Million tons	15-20	~6	30 per cent
Natural gas	Billion m3	113	-	0 per cent
Coal	Million tons	>300	-	0 per cent
Oil shale	Million tons	253	-	0 per cent

Source: Compiled from different documents of the Ethiopian Ministry of Water and Energy.

Ethiopia's capacity for electricity generation is increasing at an impressive rate. Its generation rate has grown by about 200 per cent as compared to the 2008 level. Electricity is predominantly generated from hydropower sources and accounts for about 90 per cent of the energy that is generated. However, this direction needs a cautious movement as hydropower is highly susceptible to drought which may risk the sustainability of electricity supply in the country. Despite this potential, the rural parts of the country predominantly meet their energy needs from non-renewable sources.

2.2 Definition of energy poverty

Considerable efforts have been devoted to defining energy poverty. However, the standards that have been developed rest on arbitrary assumptions with regard to the energy devices used as well as a normative definition of what a set of basic needs consist of. The context in which the definition is used such as differences in cultural and climatic conditions is of paramount importance. This has complicated the universality of a definition of energy poverty.

Nevertheless, it is possible to have a commonly used definition of energy poverty. It can be defined as the state of deprivation where a household is barely able to meet at most its minimum energy requirements for basic needs (Foster et al., 2000; Modi et al., 2006; OECD and IEA, 2010). It is also defined as lack of access to modern energy services (Li et al., 2014). Further, the concept of energy poverty has been expanded to 'an absence of sufficient choice in accessing adequate, affordable, reliable, high quality, safe and environmentally benign energy services to support economic and human development.' The energy poor have been defined as households who cannot meet their basic energy needs by estimating a minimum limit of energy consumption (Parajuli, 2011; Pereira et al., 2011). Besides, expenditure or income parameters are also used to define energy poverty. For instance, energy poverty has been defined in terms of the percentage of income spent on energy consumption. Households that spend more than 10 per cent of their incomes on energy are considered energy poor. On top of this, the multidimensional measure of energy poverty has been employed by extending energy use and access as being multidimensional in nature (Gowon and Moses, 2014; Nussbaumer et al., 2012; Sher et al., 2014). Regardless of the immense efforts devoted to the issue, as of today there is no unified definition of the concept of energy poverty. The multidimensional measure which was originally developed in the context of poverty and inequality seems to be consistent with the notion of SDGs.

Literature on energy poverty differentiates between energy poverty and fuel poverty. Some attribute these concepts to concerns of different countries on the basis of their economic status and energy systems. Energy poverty is the issue of accessibility to modern energy whereas fuel poverty is an issue of affordability. The former is a concern in developing countries, at least under the current economic status, whereas the latter is more of a concern in developed countries (Boardman, 2012). (A detailed review of the definitions of fuel poverty is available in Moore 2012).

2.3 Metric measures for energy poverty

Various measures of energy poverty have been developed and applied in literature on energy poverty. These metrics can be categorized as unidimensional and composite index measures. The former provide a powerful and unbiased measure that is easy to interpret with regard to one specific dimension and it is simple for computation. However, it is not suitable for less tangible issues such as sustainable development or poverty measures. The unidimensional measure of energy poverty tries to give metrics which could parallel the income measure of poverty with the World Bank's poverty line of $1.25 per day. Composite indexes, on the other hand, are single numerals calculated from a number of variables that represent the aggregated value of a dimension. These are advantageous over the unidimensional (dashboard) approach where we evaluate each dimension against some pre-determined, cut-off points. In the composite indices we find a single number which basically facilitates a comparison across various groups. The composite indices include the following measures:

- The Multidimensional Energy Poverty Index (MEPI)
- The Energy Development Index (EDI)

Both MEPI and EDI (Ravallion, 2010) measure access to modern energy sources. But the former evaluates energy poverty whereas the latter is a measure of an energy system's transition towards modern fuels (Nussbaumer et al., 2012). The development of the multidimensional energy poverty measure which parallels multidimensional poverty measures is a reflection of capabilities and functioning. The method is both data intensive and comprehensive as it considers non-income dimensions in the (energy) poverty measure. Notwithstanding its merits and relevance from the perspective of poverty, the method is less applicable due to paucity of data for less developed countries.

As a component of multidimensional measures and a base for unidimensional measures various indices have been developed for assessing the level and extent of energy poverty. The commonly used index of poverty measure is by Foster et al., (1984) which has been adopted to measure energy poverty as well. The three metric measures: the headcount index of energy poverty, the energy poverty gap index and the squared energy poverty gap index are frequently computed to assess the energy poverty status of households. Following Foster et al., (2000) these indices of energy poverty can be formulated as P_α:

(1) $$p_\alpha = \sum_{E_i \leq Z} \left(\frac{w_i}{N} \right) \left(1 - \frac{E_i}{Z} \right)^\theta$$

where P_α stands for the energy poverty index, w_i stands for the weight for household i, E_i stands for energy consumption for household i, Z stands for the fuel poverty line and N stands for population size. This index provides three metrics of energy poverty: intensity (head count ratio), severity (poverty gap) and depth (squared poverty gap) for $\alpha = 0$, 1 and 2 respectively.

However, the striking issue in energy poverty literature is determining the energy poverty line. Many researchers have for over 20 years been using the definition given as the minimum quantity of physical energy needed to perform such basic tasks as cooking and lighting. Others have also used a definition of the energy poverty line as the level of energy used by households below the known expenditure or income poverty line. The underlying assumption of this approach is that expenditure-based poor households are necessarily energy poor as well, which may or may not be the case (Foster et al., 2000).

Further, energy expenditure as a proportion of total income has been used to determine the energy poverty line (Boardman, 1991). This method was derived from the fact that poor households spent relatively speaking a higher percentage of their incomes on energy than wealthier ones, and spending more than a certain share of income may deprive them of other necessary goods. A cut-off point of 10 per cent of the total income has been used as the maximum share of energy expenditure allowed to remain non-poor (Barnes et al., 2011). One of the advantages of this approach is its insensitivity to price change. It is a relative energy poverty index allowing for heterogeneity in the poverty line by income classes and locations. The same authors have also developed another method which is similar to the expenditure method to define the energy poverty line. For the alternative method they use a demand-based approach as the threshold point at which energy consumption begins to rise with an increase in household income. At or below this threshold point, households consume a bare minimum level of energy and should be considered energy poor. Besides this, some authors have also proposed a median approach, when income distribution is skewed, to determine the energy poverty line.

Definition of energy poverty and determining the cut-off (the energy poverty line), however, need to be approached with a caution. The conventional way of defining poverty and the poverty line do not serve this purpose. In the case of conventional goods, higher consumption means a higher level of welfare or lower level of poverty. But for energy goods, more consumption may not necessarily lead to higher welfare due to the fact that the demand for energy is a derived demand. Higher consumption of energy perhaps leads to lower welfare due to its repercussions on the environment, human health and budget claims. In this paper we employ the multidimensional measure of energy poverty following the Nussbaumer et al., (2012) methodology.

2.4 Empirical Literature

This section presents a summary of empirical works on energy poverty for different regions. The survey is chronologically presented in Table 3 to show past developments and the state of research at present.

Table 3. Summary of empirical studies on energy poverty

No	Author(s)	Year	Country	Energy poverty definition and analysis
1	Pachauri & Spreng	2004	India	Two-dimensional/Engineering method
2	Barnes et al.	2011	Bangladesh	Demand based
3	Pereira et al.	2011	Brazil	Used the conventional analytical frame-work (Lorenz curve, gini coefficient etc.)
4	Nassbaumer et al.	2012	Some African countries	MEPI
5	Khandker et al.	2012	India	Demand based
6	Tchereni et al.	2013	Malawi	Energy expenditure
7.	Edoumiekumo et al.	2013	Nigeria	MEPI
8.		2015	Ethiopia	MEPI

Various researchers have examined energy poverty in different countries. This brief review of the developments in literature on the measurement of energy poverty for different countries indicates that researchers have used various methods and the results of their analyses vary considerably. Even though energy poverty is a pressing issue for developing countries especially for sub-Saharan Africa, there are very few studies on this issue in SSA countries. For example Tchereni et al., (2013) conducted an economic analysis of energy poverty for Malawi. They show that various socioeconomic variables determined the energy poverty status of households. Similarly, Edoumiekumo et al., (2013) employed the multidimensional measure of energy poverty to show the extent and determinants of energy poverty in Nigeria. Their results of multidimensional energy poverty show that the country has severe energy poverty with some regional variations. Moreover, their regression results from the multinonial logit model show that socioeconomic, geographic and demographic variables affect the probability of households falling into different energy poverty statuses. For Ethiopia there is paucity of research on this issue. Very few studies are available and those which are available have limitations in terms of the area covered and the methodology employed. For instance, the Bekele et al.'s (2015) study is geographically limited to only Addis Ababa. Therefore, it is expected that the current paper will bridge this gap in literature. Further, this study employed the multidimensional measure of energy poverty following the family of decomposable measures of multidimensional poverty proposed by Alkire and Foster (2007) and recently modified as the multidimensional measure of energy poverty index (MEPI) by Nasshaumer et al., (2012).

3. Data and Methodology

3.1 Data sources and types

The data used for this study is a combination of secondary data obtained from various sources. Primarily, the study relied on secondary data collected by the Central Statistical Agency of Ethiopia and World Bank (CSA & WB). It also employed data from the Internatonal Energy Agency-World Energy Outlook database. Two waves of data from the Ethiopian Socioeconomic Survey (ESS) which is a collaborative project between CSA and the World Bank Living Standards Survey were also used. The first wave of the data was collected in 2011 and the second in 2014 which was finally released in March 2015. The survey is very comprehensive and is multi-topic that can be flexibly used for welfare analyses using different attributes. The first wave of the survey covered almost all the rural parts of the country and small towns.

As part of the first survey, information was collected from 3,969 respondents in all regions of the country. In its second wave, the survey extended the sampling frame by including respondents from large urban areas including capital Addis Ababa. By doing this it tried to maintain the representativeness of the data collected from the sample respondents. The second round of the survey collected information from 5,262 respondents of which 3,776 were from the first wave. The two waves are expected to gradually form panel data where households are observed over time. The panel attrition rate between the two current waves is only 5 per cent or the two-year panel success rate is about 95 per cent which can be safely used for a simple panel data analysis following households' energy use behavior over time. As a result, this study used information from 3,776 respondents in rural and small towns in Ethiopia which were covered in both the rounds of the survey. (For a detailed description of the dataset see CSA & WB, 2011, 2014).

3.2 The multidimensional measure of energy poverty

The striking issue in measuring energy poverty is availability of detailed data on various dimensions of households' energy use. The selection of variables/indicators in constructing the multidimensional measure of the energy poverty index (MEPI) is subject to the availability of data. Besides, determining the relative importance of each variable in constructing MEPI is crucial. Following literature on the multidimensional measure of energy poverty and data availability, the following attributes are identified as indicators of energy use status of households in rural and small towns in Ethiopia:

The index is composed of five indicators forming an index with four dimensions. The first indicator identified is type of energy sources used by households for cooking. It is clear that all households use energy for cooking their daily food. However, the type of energy sources they use to generate this heat affects their welfare. Use of traditional energy sources (firewood, charcoal, dung or crop residuals) cause many inconveniences and entail great opportunity costs (such as time allocated for collecting them). The second dimension is extent of indoor air pollution. Dependence on traditional sources of energy and using inefficient energy use technologies among other things exposes households to higher risks of indoor air pollution. Indoor air pollution threatens the health and lives of many rural households in developing countries. Women and children are highly prone to externalities of cooking. This in turn creates health risks and reduces the welfare of the households (HDR, 2014; WHO, 2002). As a result, inclusion of variables which can proxy this problem is very crucial in computing the multidimensional index of energy poverty. Two variables are used to measure the risk and health burden of indoor air pollution: kitchen and type of stove used. The third indicator is type of energy used for lighting and finally ownership of entertainment and educational assets are used to construct the multidimensional measure of energy poverty. Details of the variables, indicators, weights used and deprivation cut-offs for computing MEPI are given in Table 4.

Table 4. Description of attributes, variables and their cut-off points for computing MEPI

No.	Dimension	Indictor	Variables (weight)	Deprivation cut-off (poor if…)
1	Cooking (C_i)	Modern cooking fuel	Type of cooking fuel (0.25)	Use traditional sources of energy[3] for cooking
2	Pollution (IP_i)	Indoor air pollution	Kitchen is separate (0.15)	Use same residential house for cooking or no kitchen
			Type of oven/mited used for cooking (0.15)	Use traditional cook stove or use a three stone cook stove
3	Lighting (HF_i)		Type of energy used for lighting (0.25)	Household is deprived if it does have electricity for lighting
4	Entertainment & Education (EE_i)	Entertainment or educational appliance ownership	Has a radio, tap, TV or satellite dish (0.20)	A household is considered poor/deprived if it has none of these assets

On the other hand, multidimensional energy poverty is analytically constructed from the dimensions identified with weights estimated or assigned to show the level of energy deprivations that may affect households' welfare. The construction of MEPI follows the

[3] Traditional sources of energy in this context refer to biomass such as firewood, charcoal, dung and crop residuals while modern energy sources include electricity, kerosene, LPG and natural gas.

multidimensional poverty measure developed by scholars at the Oxford Poverty and Human Development Initiative (OPHI) (Alkire, 2007; Alkire and Foster, 2007, 2011; Alkire and Santos, 2014). Their initiative was influenced by Amartya Sen's groundbreaking work on deprivations and capabilities with the central argument that human poverty should be considered as the absence of opportunities and choices for living a basic human life (Sen, 1990).

This energy deprivation status of a household is constructed using four dimensions with five indicators. A household is said to be energy poor if the deprivation exceeds pre-defined cut-off points. Following Nussbaumer et al., (2012) we define multidimensional energy poverty status of households as follows: multidimensional energy poverty is measured in d variables for the sampled households (n). A vector $Y=\{y_{ij}\}$ represents the n×d matrix of achievements for i households across j variables. The value of $y_{ij}>0$, therefore, it represents household i's achievement in the j^{th} variable. From these household level achievements using the dual cut-off approach we constructed the extent and severity of multidimensional energy poverty for each household and aggregated it to the population level.

The multidimensional energy poverty line of 0.33 is adopted. A household is energy poor if it is deprived of more than 33 per cent of the indicators. Hence, a household whose sum of weighted deprivation is greater than or equal to 0.33 is categorized as energy poor and a household whose sum of weighted deprivation is less than 0.33 is energy non-poor.

The multidimensional energy poverty index (MEPI) is then computed as:

Energy Poverty Headcount:

(2) $$H = \frac{1}{N}\sum_{i=1}^{q} c_i > k ,$$

where k stands for the energy poverty line, c_i stands for households whose deprivation score is higher than the cut-off point. The energy poverty head count (H) measures the incidence of energy poverty. It is the percentage of households whose deprivation score is above the cut-off point.

Energy poverty intensity:

(3) $$A = \sum_{i=1}^{q} c_i(k) \Big/ \sum_{i=1}^{q} c_i ,$$

where $\sum_{i=1}^{q} c_i(k)$ is the censored weighted deprivation score of the household. Finally, MEPI is computed from both incidence and intensity of energy poverty as:

(4) MEPI = H*A

3.3 Econometric analysis of energy poverty

The aim of this study is to determine the energy poverty state of households. The index computed provides a measure of energy poverty. In line with literature, in the second step the households are classified as energy poor and energy non-poor. This allows analyzing the multidimensional measure of energy poverty and its determinant using a panel logit model. In the logit model the dependent variable is the multidimensional energy poverty index. It is transformed into binary choice by using a specified deprivation cut-off point for the energy poverty index. If the index is greater than 0.33 the household is considered to be energy poor multi-dimensionally. The threshold is chosen based on the assumption of minimum required energy to satisfy the normal needs of a household considering the four dimensions described earlier.

3.4 Specification of the econometric model

The theoretical foundation for the specification of this model is driven from the latent variable approach. Suppose that a household's energy use is specified as:

$$(5) \qquad y^*_{it} = x_{it}\beta + c_i + u_{it}$$

However y^*_{it} is not observable by a researcher, what the researcher observes is only that based on the threshold that the household under consideration is energy poor or not. As a result the analyst can initiate specifications and estimations of binary choice models from the latent variable specification to identify and estimate the effects of the determinants of household energy poverty:

$$(6) \qquad y_{it} = \begin{cases} 1 \ \text{ if } y^*_{it} > 0 \\ 0, \ \text{ otherwise.} \end{cases}$$

Now the probability that y_{it} takes the value of one of the given covariates and individual unobserved heterogeneity can be written as:

$$(7) \qquad pr\left(y_{it} = 1 \mid x_{it}, c_i\right) = F\left(x_{it}\beta + c_i\right),$$

where F(.) is either the standard normal CDF (probit model) or the logistic CDF (logit model). From this non-linear model individual heterogeneity (c_i) cannot be removed easily by differencing using within transformation or inclusion of the individual dummy variable to estimate (c_i) since it results in biased estimates unless t is very large. This will lead to the problem of incidental parameters (small T bias) (Cameron & Trivedi, 2005). Thus, we can estimate non-linear panel models with random effect or fixed effect logit or probit models. In this paper assuming the logistic distribution, we can specify our logit model as:

$$(8) \qquad \begin{aligned} pr\left(y_{it} = 1 \mid x_{it}, c_i\right) &= \Lambda\left(x_{it}\beta + c_i\right) \\ pr\left(y_{it} = 1 \mid x_{it}, c_i\right) &= \frac{\exp\left(x_{it}\beta + c_i\right)}{1 + \exp\left(x_{it}\beta + c_i\right)} \end{aligned}$$

The traditional random effect logit model under the following assumption is used to estimate the determinants of multidimensional energy poverty in rural and small towns in Ethiopia. It requires strict exogeneity and zero correlation between the explanatory variables (x) and individual heterogeneity (c_i). The final estimable model for identifying and examining the effects of the determinants of multidimensional energy poverty in rural and small towns in Ethiopia used characteristics of a household's head (age, sex, education level, marital status); household characteristics (family size, expenditure on energy, total household expenditure, credit use and number of rooms); and nature of residential area (rural or small town). After the estimation of the random effect logit model, the log odds ratio and marginal effects were estimated to get interpretable results.

The odds ratio obtained from the logit model which shows the ratio of success to failure can be specified as:

(9)

$$\left(\frac{pr\left(y_{it}=1\mid x_{it},c_i\right)}{pr\left(y_{it}=0\mid x_{it},c_i\right)}\right)=\frac{\exp\left(x_{it}\beta+c_i\right)}{1+\exp\left(x_{it}\beta+c_i\right)}\Bigg/1-\frac{\exp\left(x_{it}\beta+c_i\right)}{1+\exp\left(x_{it}\beta+c_i\right)}$$

$$=\exp\left(x_{it}\beta+c_i\right)$$

If we take the log of the odds ratio we get the log odds ratio as:

(10)

$$\log\left(\frac{pr\left(y_{it}=1\mid x_{it},c_i\right)}{pr\left(y_{it}=0\mid x_{it},c_i\right)}\right)=\log\left(\exp\left(x_{it}\beta+c_i\right)\right)$$

$$=x_{it}\beta+c_i$$

Finally the marginal effect for the determinants of energy poverty based on the logit model parameter estimates is obtained from the following relation:

(11)

$$\partial\Pr\left(y_{it}=1\mid x_{it},c_i\right)\Big/\partial x_{jit}=\beta_j\Lambda\left(x_{it}\beta+c_i\right)\left\{1-\Lambda\left(x_{it}\beta+c_i\right)\right\}$$

The odds ratio and marginal effects are among the generated results which are used for an interpretation. As we can see from Eqn. 11 the marginal effect of the x-variables based on the logit is non-linear. This implies that the interpretation of the logit model should be treated with caution.

4. Results and Discussion

The first part of this section presents descriptive statistics of important variables to highlight and give a clear picture of the data used for the study. It starts with a presentation and discussion of the demographic characteristics of the respondents. It then extends to a description of the socioeconomic characteristics of the households. It finally presents the status of households in energy related activities with due emphasis on the variables used for constructing the multidimensional energy poverty index. This part gives energy access and energy use technology ownership status of the households. As such it shows the energy poverty status of the households qualitatively or gives the dashboard indicator of the deprivation levels of households. In the second part it gives an analysis of energy poverty using a multidimensional approach in detail. It then presents the econometric results to examine the determinants of multidimensional energy poverty in rural and small towns in Ethiopia.

4.1 Descriptive statistics of the demographic characteristics

The demographic characteristics of the households and their heads for the two waves of the data are presented in Table 5.

Table 5. Household size, age and sex of head (by year)

	Year			
	2011		2014	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Household size (in number)	4.86	2.38	5.00	2.39
Household head's age (in years)	44.24	15.64	45.84	15.32

Source: Researcher's computation from ESS 2011 and 2014 data.

As can be seen from Table 5, family size of the sample respondents was about 4.86 in 2011 with a standard deviation of 2.38. In the second round of data collection the mean family size was slightly higher than it was in the first round. In 2014 average family size of the respondents was five persons per household with a standard deviation of 2.39. This may tell us that family planning needs to be reconsidered if the country wants to keep population growth within reasonable dynamics. Further, Table 5 shows that the average age of the household head was about 44.24 and 45.84 years in 2011 and 2014 respectively. It shows that the average age of the head of the household was slightly higher in 2014 as compared to 2011.

Table 6. Percentage of sex, religion and marital status of the head of household (by year)

	Year	
	2011	2014
Variable	Per cent (per cent)	Per cent (per cent)
Household head's sex Male (per cent)	75.48	74.12
Household head's sex Female (per cent)	24.52	25.88
Household head's religion Orthodox (per cent)	43.83	43.77
Household head's religion Muslim (per cent)	32.79	33.23
Household head's religion Protestant (per cent)	19.65	19.70
Household head's religion Others (per cent)	3.73	3.30

Single	3.83	3.36
Married	76.28	74.49
Divorced	5.47	6.83
Separated	1.91	1.36
Widowed	12.52	13.96

Source: Researcher's computation using ESS 2011 and 2014 data.

A detailed exploration of the data in Table 6 shows that there was not much variation in the headship and religion of the head of the household in the two rounds of the survey. The headship role was predominantly played by males which may call for various policies to empower women and their role in resource use and decisions in the household. Besides, the religion of the head of the household shows a slight variation in the two survey periods.

The marital status of the head of the household shows that a majority of the respondents were married (about 76.28 per cent and 74.49 per cent in 2011 and 2014 respectively). Table 6 further shows that a very low proportion of the respondents was single or separated in both rounds of the survey.

Table 7 presents the expenditure patterns of households on different items in 2011 and 2014. There is an observable variation in expenditure patterns in the survey years. In the first round food and energy expenditures were on average higher than in 2014. But expenditure on non-food items shows slightly higher value on average in 2014 as compared to 2011. Moreover, the pattern of expenditure shows that there was wider dispersion which indicates the extent of inequality in the study area and hence implies relevant policy interventions to improve the situation.

Table 7. Descriptive statistics of important variables (by year)

	Year			
	2011		2014	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Annual food expenditure	8,843.56	48,391.32	6,723.93	10,573.76
Annual energy expenditure	665.97	6,179.88	642.35	2,067.00
Annual non-food expenditure	1,439.25	8,879.73	1,631.07	3,070.07
Annual non-food expenditure (fixed assets)	2,224.09	13,886.54	2,964.07	5,356.31
Annual total expenditure	12,506.91	53,249.59	11,319.07	14,101.73

Source: Researcher's computation from ESS 2011 and 2014 data.

4.2 Descriptive statistics of energy sources and technology use of households

The data from the two rounds of the survey contain important information about the energy use status of households. Residents in most developing countries, especially in rural parts rely on inefficient energy use technologies and energy sources to meet their daily needs. This is partly due to the non-availability of alternative sources and due to their non-affordability. As we can see from Table 8, a majority of the households used biomass as a source of energy for cooking. Firewood (either collected or purchased) was the major source of energy for cooking for about 87 per cent of the households in rural and small urban areas. This predominance of energy use for cooking has significant implications for health, time use and negative environmental impacts. Very few households used modern energy sources as a major source of cooking energy.

Table 8. Main sources of cooking fuel

	Year	
	2011	2014
Variable	per cent (per cent)	per cent (per cent)
Collecting firewood	78.04	77.62
Purchase firewood	9.80	9.71
Charcoal	1.61	1.52
Crop residuals/leaves	3.24	3.30
Dung/manure	5.01	5.30
Sawdust	0.08	0.03
Kerosene	0.62	0.69
Butane/gas	0.03	0.11
Electricity	0.13	0.64
Solar	0.03	0.00
Other sources	1.42	1.10

Source: Researcher's computation from ESS 2011 and 2014 data.

Table 9 shows that electricity, solar, kerosene and butane/gas made an almost insignificant proportion of energy sources for cooking of the respondents in rural and small towns in Ethiopia. This requires an aggressive energy policy and interventions to ameliorate the situation.

Table 9. Main source of energy for lighting households (by year)

	Year	
	2011	2014
Variable	per cent (per cent)	per cent (per cent)
Electricity meter- private	7.64	7.90
Electricity meter- shared	9.65	12.35
Electricity from generator	0.45	0.50

Solar energy	0.13	3.05
Electric battery	0.29	0.50
Light from dry cell with switch	17.29	25.64
Kerosene light lamp (imported)	9.75	5.78
Kerosene light lamp (local kuraz)	41.23	33.54
Candle/wax	0.24	0.08
Firewood	12.99	9.68
Other sources	0.32	0.98

Source: Researcher's computation from ESS 2011 and 2014 data.

Table 9 shows the status of energy sources for lighting in rural and small towns in Ethiopia. A further look at the data shows that the primary energy source for lighting was kerosene light (local kuraz) and firewood.

Table 10. Type of kitchen used by households for preparing food

	Year	
	2011	2014
Variable	Per cent (per cent)	Per cent (per cent)
A room used as a modern kitchen outside	0.35	0.56
A room used as a modern kitchen inside	0.32	0.64
A room used as a traditional kitchen outside	32.70	36.40
A room used as a traditional kitchen inside	23.27	28.95
No kitchen	43.36	33.46

Source: Researcher's computation from ESS 2011 and 2014 data.

Indoor air pollution is a very severe problem in developing countries which predominantly use traditional sources of energy for preparing their daily food (see Table 10). Besides the type of energy used, the type of kitchen and energy use technologies play a crucial role in reducing indoor air pollution. Energy use technology has an immense role in reducing indoor air pollution, quantity of energy used for cooking or lighting and saving time for households. Cooking in most of the developing countries demands a lot of time and uses considerable energy and claims a higher resource budget of poor households. As a result, improving energy use efficiencies of these technologies and promoting technologies reduces energy use related burdens on the environment and enhances households' welfare to a greater extent. As can be seen from Table 11 about 97 per cent of the households used traditional stoves for cooking. The figure does not show any improvement in the 2014 survey.

Table 11. Primary type of stove (mitad) used - baking enjera

	Year	
	2011	2014
Variable	Per cent (per cent)	Per cent (per cent)
Traditional mitad (removable)	68.68	72.48
Traditional mitad (not removable)	28.33	25.24
Improved energy saving mitad (rural tech.)	2.70	1.91
Electric mitad	0.29	0.93

Source: Researcher's computation from ESS 2011 and 2014 data.

4.3 Extent of energy poverty in rural and small towns in Ethiopia

The results of the deprivation analysis show that the sample households were severely deprived of modern energy services and hence we see evidence of widespread energy poverty in rural and small towns in Ethiopia. The head count measure of the deprivation status of households when it comes to energy services is presented in Table 12.

Table 12. Head count measure of deprivation status by year (dashboard approach)

	Year	
	2011	2014
Variable	Per cent (per cent)	Per cent (per cent)
Deprivation of cooking fuel	99.20	98.57
Deprivation of type of kitchen	66.92	62.42
Deprivation stove types	97.03	97.16
Deprivation of lighting source	82.28	76.21
Deprivation of education or entertainment	63.79	68.53

Source: Researcher's computation from ESS 2011 and 2014 data.

As can be seen from Table 12 the dashboard approach shows the extent of deprivation of energy sources or services by each indicator. A further look at the results shows that there was some improvement in deprivation levels in 2014 as compared to 2011. However, the change is not very impressive which suggests that the sector needs concerted policy interventions.

Table 13. Multidimensional index of energy poverty indices by year (the Alkire and Foster, AF 2007 method)

	Year	
	2011	2014

Group variable	MEPI	MEPI
Male	73.3	71.3
Female	78.9	76.6
Population	74.4	73.2

Source: Researcher's computation from ESS 2011 and 2014 data.

Energy poverty is prevalent in most of the developing countries. The case is peculiar for rural parts of SSA countries where most of the population is deprived of access to modern energy sources. Modern energy sources are both physically and economically not accessible in rural parts. Physical accessibility means the availability of energy sources in the area. For example, the rate of rural electrification is very low which implies that electricity is not physically accessible to rural residents. More importantly, economic accessibility is challenging for rural residents for switching to modern energy and improved energy technologies. Low income/poor households cannot afford to pay for modern energy and improved technologies which forces them to use traditional sources of energy and energy use technologies.

The case is acute for rural and small urban areas in Ethiopia. As we can see from Table 13, the multidimensional measure of energy poverty shows the existence of severe energy poverty. About 74 per cent of the households were multi-dimensionally energy poor in 2011 while there was only a slight decline in the second round of the survey. Female headed households were more energy poor as compared to male headed households in both the years.

Table 14. Relative contribution of dimensions to Alkire and Foster (AF) MEP indices estimated as population share (in per cent)

	Year	
	2011	2014
Dimensions	MEPI	MEPI
Type of cooking fuel	43.20	40.43
Type of kitchen used	18.12	20.37
Type of stove used	10.60	15.52
Source of energy for lighting	8.48	10.36
Ownership of educational/entertainment appliances	19.6	13.32

Source: Researcher's computation from ESS 2011 and 2014 data.

Table 14 shows the contribution of each dimension to the multidimensional index of energy poverty for households. This information can be used for targeting each dimension if one wants to reduce energy poverty in the study area. The dimensional deprivation shows that any attempts to solve the problem of energy poverty in the study area should target each dimension with varying degrees of emphasis.

4.4 Determinants of MEPI in rural and small towns in Ethiopia

Once we have examined the extent of energy poverty in the study area, the next step is to examine the factors that are responsible for this level of energy poverty for the households. Using the random effect logit model we examined the determinants of multidimensional energy poverty for households in rural and small urban areas in Ethiopia. The regression results using socioeconomic characteristics, household head's characteristics and community characteristics are given in Table 15. Before running the regression we conducted a series of diagnostic tests to see whether the data fulfilled some desirable properties. The presence of multi-collinearity, normality of the variables and specification tests were conducted using appropriate tools. To correct for unknown forms of the heteroscedasticity problem that may reduce efficiency of the estimated coefficients we used White's heteroscedasticity consistent standard error (robust estimation). The results of the random effect logit model and marginal effects after logit are given in Tables 15 and 16 respectively.

Table 15. Logit regression results of determinants of MEPI

MEPI_index	Coefficients	Std. Err.	p-value
Household's size	0.13	0.06	0.022
Sex of HH head (male=1, female=0)	0.69	0.32	0.031
Household head's age	-0.02	0 .01	0.047
Literacy (1 literate 0 otherwise)	1.62	0.38	0.000
Area of residence	1.80	0.27	0.000
Number of rooms for HH	-0.34	0.08	0.000
Credit use (1 if used, 0 otherwise)	-0.26	0.30	0.384
HH energy expenditure (log)	-0.05	0.10	0.654
HH total expenditure (log)	-0.72	0.15	0.000
Marital status (married=1 or otherwise)	0.82	0.41	0.045
Marital status (divorced=1 or otherwise)	1.48	0.60	0.013
Marital status (separated=1 or otherwise)	0.53	1.10	0.631
Marital status (widowed=1 or otherwise)	1.37	0.64	0.032
Constant	8.13	1.22	0.000

Note: N=6,533, Log likelihood = -322.91, Pseudo R^2= 0.30, Wald chi2(13) = 211.49***.

Since the logit model's results are not directly interpretable we have to compute either the log odds ratio to interpret the estimated results as the effect of independent variables on the probability of success to failure ratio, or alternatively we can compute marginal effects after logit and interpret the results directly as the effect of covariates on the probability of being energy poor. We prefer the results of the marginal effect after logit since these give us the effect of covariates on the probability of being multi-dimensionally energy poor.

Table 16. Marginal effect after the logit model

Variable	dy/dx	Std. Err.	P>|z|
Household's size	0.0004	0.0002	0.028
Sex of HH head (male=1, female=0)	0.0024	0.0014	0.093
Household head's age	-0.00005	0 .00003	0.058
Literacy (1 literate 0 otherwise)	0.005	0.0011	0.000
Area of residence	0.011	0.0034	0.001
Number of rooms for HH	-0.001	0.0003	0.002
Credit use (1 if used, 0 otherwise)	-0.00074	0.00086	0.385
HH energy expenditure (log)	-0.00013	0.0002	0.655
HH total expenditure (log)	-0.002	0.0005	0.000
Marital status (married=1 or 0 otherwise)	0.003	0.0020	0.135
Marital status (Divorced=1 or 0 otherwise)	0.002	0.0007	0.001
Marital status (Separated=1 or 0 otherwise)	0.001	0.0018	0.520
Marital status (Widowed=1 or 0 otherwise)	0.002	0.0009	0.008

The results in Table 16 show that as household size increases by one member the probability of the household falling into multidimensional energy poverty increases by 0.0004 which is significant at the 5 per cent level of significance. Male headed households have about 0.0024 higher probability of becoming multi-dimensionally energy poor as compared to female headed households. A one year increase in the age of the head of the household decreases the probability of the household becoming multi-dimensionally energy poor by 0.00005 and is significant at 10 per cent. Access to credit, more rooms occupied and higher household total expenditure significantly reduce the probability of a household falling into energy poverty.

5. Conclusions and recommendations

This study examined in detail the extent and determinants of energy poverty in rural and small towns in Ethiopia. The study used two rounds of overlapping data from a survey conducted in a joint project of the Central Statistical Agency of Ethiopia and the World Bank as part of the Living Standards Survey. With the primary objective of analyzing the extent and determinants of multidimensional energy poverty in the study area, the paper highlighted the status of households with regard to energy use and energy use technologies in the area. The descriptive statistics' results clearly revealed energy use status of the respondents in both the survey years.

The study also examined the extent of energy poverty in the area using the multidimensional measure following the Nussbaumer et al., (2012) methodology adopted from Alkire and Foster (2007) as the multidimensional measure of poverty. The results of the multidimensional energy poverty index show that about 74.4 per cent and 73.2 per cent of the respondents were multi-dimensionally energy poor in 2011 and 2014 respectively. The results also showed that there was no significant improvement in the energy poverty status of the households in the survey periods with a three-year difference. The relative contribution and decomposition of multidimensional energy poverty by dimension can help policymakers and development planners direct resources and efforts in appropriate intervention areas. Specifically, policy interventions for improving households' energy poverty should consider each attribute and design appropriate tools for public intervention.

On the other hand, results from the random effect logit model showed determinants of MEP status of the households. Households with larger family size, married, widowed or divorced household heads and located in rural areas had a higher probability of being multi-dimensionally energy poor. On the contrary, higher age of the head of the household, access to credit, more rooms occupied and higher total household expenditure (proxy for income) reduced probability of households being multi-dimensionally energy poor. As noted in literature and confirmed by the positive coefficient of income on energy poverty from the regression results of this study, enegy poverty is highly correlated with income poverty. As income increases, the energy poverty level decreases which implies that affordability of energy sources and energy use technologies require a series of policy interventions. Policies promoting clean energy technology and clean energy sources should be supported to enhance households' incomes. Moreover, the results of the study show that the Government of Ethiopia has a long way to go still to realize rural clean energy access regardless of the relentless efforts that have been made so far. More efforts are required for promoting rural clean energy and energy use technologies (for example, through rural electrification and promoting solar energy) coupled with an appropriate pricing mix (subsidy) to reach the poor and thus reducing energy poverty.

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