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# Determinants of household energy choice for domestic chores: Evidence from the Semien Mountains National Park and Adjacent Districts, Northwest Ethiopia

Belete Debebe[a,*], Feyera Senbeta[b], Dawit Diriba[b], Ermias Teferi[b], Demel Teketay[c]

[a] Department of Population Studies, College of Social Sciences and Humanities, University of Gondar, Gondar, P.O. Box 196, Ethiopia; [b]Center for Environment and Development Studies, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

[b] Center for Environment and Development Studies, College of Development Studies, Addis Ababa University, Addis Ababa, P.O. Box 1176, Ethiopia

[c] Department of Range and Forestry Resources (RFR), Faculty of Natural Resources, Botswana University of Agriculture and Natural Resources (BUAN), Gaborone, South East 00000, Botswana

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ABSTRACT

Energy is a cornerstone and strategic tool to meet basic human needs and address many global development challenges. However, ensuring energy supply while limiting energy's contribution to environmental change is a major challenge confronting the energy sector in many developing countries. The challenge is more severe in Sub-Saharan Africa, where about 900 million people still rely on biomass fuels for cooking. Cooking with biomass might not be a problem by itself. Instead, it is the inability to use biomass energy resources sustainably. Improving the opportunities for modern and sustainable energy use is, thus, an essential prerequisite to enhancing the livelihoods of the poor. This study examines the determinants of household energy choice in the Semien Mountains National Park and adjacent districts in Northwest Ethiopia. A survey of 420 randomly selected households was administered using a semi-structured questionnaire. Descriptive statistics and a multivariate probit model were employed to analyze the data. Results showed that households' energy utilization pattern is skewed towards biomass fuels, particularly fuelwood (87%), while only a few households use charcoal (32%) and electricity (17%) for domestic chores. The study also shows that the majority (87%) of households collect all of their energy sources themselves, while 13% purchase from the market. In addition, the results show that about 77% of households perceived that fuelwood availability had decreased over time owing to deforestation. Estimates of the multivariate probit model showed that a mix of factors, including age, gender, household size, education, income, access to electricity, off-farm activities, access to market, distance to forest, and housing type, determine household cooking energy choice and the extent of dependency on it. Thus, the findings proved that local communities prefer fuel stacking rather than ascending the energy ladder. Based on the results, the study recommended that the local community be encouraged to use biomass fuels in a more environmentally friendly way and use sustainable and affordable modern energy sources.

## 1. Introduction

Energy is a cornerstone and strategic tool to attain basic human needs and address many global development challenges (Kowsari and Zerriffi, 2011; Nussbaumer et al., 2012; IEA, 2018; Martey, 2019). Most development goals, including the Sustainable Development Goals (SDGs), demand a sustainable supply of energy resources that is sustainably available at a reasonable cost and can be utilized for all required tasks without causing negative societal and environmental impacts (Sopian et al., 2011). However, ensuring energy supply while limiting energy's contribution to environmental change is a major challenge confronting the energy sector in many developing countries (Kaygusuz, 2011).

*Abbreviations:* ANRS, Amhara National Regional State; EWCA, Ethiopian Wildlife Conservation Authority; FDRE, Federal Democratic Republic of Ethiopia; IAP, Indoor Air Pollution; IEA, International Energy Agency; IRENA, International Renewable Energy Agency; MEFCC, Ministry of Environment, Forest, and Climate Change; MNL, Multinomial Logit; MVP, Multivariate Probit; SDGs, Sustainable Development Goals; SMNP, Semien Mountains National Park; SSA, Sub-Saharan Africa; WB, World Bank; WHO, World Health Organization.

* Corresponding author.
*E-mail address:* belebete@yahoo.com (B. Debebe).

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The problem is more severe in Sub-Saharan Africa (SSA), with some 890 million people still relying on traditional biomass fuels for their basic energy needs (IEA, 2018). This is a cause of concern because biomass fuels have severe consequences on human health and the environment at large (Twumasi et al., 2020). A recent study by Imran et al. (2019) indicates that burning biomass fuel directly in open fires causes indoor air pollution (IAP) that harms the health of women and children. According to WHO (2018), nearly 4 million people die yearly from IAP exposure to inefficient cooking practices. Aside from health concerns, burning biomass fuels contribute to climate change by emitting $CO_2$ into the atmosphere (Muller and Yan, 2018). This further damages agricultural productivity (Pandey and Chaubal, 2011) and threatens the nutritional health of human beings (Muller and Yan, 2018).

As Van Der Kroon et al. (2013) pointed out, biomass fuel usage in traditional and inefficient cooking stoves requires more fuel, thereby putting a burden on women and children to allocate extra collection time (Foell et al., 2011; Karimu, 2015). These practices prevent women and children from earning a living or pursuing education, respectively (Lewis and Pattanayak, 2012). Unsustainable fuelwood harvesting further degrades local forests and woodlands, all of which contribute to land degradation and climate change (Foell et al., 2011). Switching to modern fuels, therefore, provides many potential benefits, such as improving the welfare of women by providing them with the opportunity to engage in income-earning activities as a consequence of the efficiency and reduced time required for cooking (Karimu, 2015). In light of the issues associated with energy, it is important to understand the key variables that influence household fuel choice and transition (Twumasi et al., 2020), which will help policymakers formulate and promote appropriate energy policies to support energy transition.

Ethiopia, with a population of 115 million in 2020, is Africa's second-most populous country after Nigeria (PRB, 2020). Providing adequate energy sources for the country's growing population is a challenge now and in the future. Economic development requires increasing energy demand, but limited access to affordable and clean energy remains an important barrier to achieving development goals (Mondal et al., 2018). Ethiopia is potentially endowed with a variety of energy sources: hydropower, wind, solar, geothermal as well as biomass (Mondal et al., 2017). However, these have not yet been developed to economically optimal levels, and many households are experiencing severe energy problems (Mengistu et al., 2016). Ethiopia, for example, lags behind other SSA countries in many ways, including energy. In 2017, modern energy: electricity shared approximately 13% of the total energy consumption (Tiruye et al., 2021). Per-capita electricity consumption was about 93 kWh per year, which is significantly lower than the average per capita energy consumption in SSA (521 kWh/capita/year) (MoWE, 2012). Moreover, according to the Multidimensional Energy Poverty Index report, Ethiopia scored 0.9, indicating severe energy poverty (Nussbaumer et al., 2012).

Ethiopia has faced several challenges as it has strived to promote modern and clean energy at the household level. Biomass is Ethiopia's primary energy source, accounting for about 88% of the total energy supply (Tiruye et al., 2021). Apart from biomass, other primary energy sources include electricity and petroleum, collectively accounting for 9.3% (Mondal et al., 2018). Household is a primary energy-consuming sector, accounting for 88% of total energy consumption in Ethiopia (Getie and Degefa, 2019; Pappis et al., 2021; Tiruye et al., 2021). The primary end-use of biomass fuel is for domestic cooking and baking (MoWE, 2012), which accounts for over 60% of household energy consumption (Gebreegziabher et al., 2012).

Various studies have shown that excessive reliance on biomass fuel negatively affects the environment as it causes deforestation (Guta, 2014; Gebreegziabher et al., 2017). Between 1990 and 2010, for instance, the average annual rate of deforestation in Ethiopia was nearly 1% (FAO, 2010), which is one of the highest in the world, and household energy utilization patterns, particularly fuelwood use, play a major role (Tucho and Nonhebel, 2015). As a result of indiscriminate felling and exploitation of trees for fuel, greenhouse gas emissions are expected to increase from 24 Mt of $CO_2$ in 2010 to 41 Mt of $CO_2$ in 2030 if no action is taken (FDRE, 2011). Besides, the excessive use of fuelwood leads to ecological imbalance and degradation of forest cover without regeneration (Negash and Kelboro, 2014), which in turn has led to millions of populations suffering from energy scarcity (Guta, 2014).

In response to the challenge to access and low household consumption of modern and clean energy sources, the Government of Ethiopia has clearly outlined its path to accessing modern and clean energy sources in its medium-term development plans (GTP-I and GTP-II) (FDRE, 2019). The plan has remained relevant in transforming the landscape of household energy consumption and preferences to build and disseminate renewable energy technology (Marie et al., 2021; Tiruye et al., 2021). However, despite the policy giving priorities, consumption of modern and clean energy sources remains relatively low at the household level. Moreover, the Government, in conjunction with Non-Government Organizations (NGOs) and donors, has made significant efforts to increase access to and use of modern and clean energy sources (FDRE, 2011). Accordingly, rural electricity coverage has increased from 2% in 2000 to 33% in 2018 (IEA, IRENA, WB, WHO, 2020), and the dissemination of fuel-efficient cooking stoves has grown (>10%) in recent years (MEFCC, 2018). However, despite recent advances in modern and clean energy in Ethiopia and the Amhara region, substantial knowledge gaps persist regarding the determinants of household energy choices and factors that hinder the transition to modern fuels.

Amhara region is suffering from a significant domestic energy crisis, which can be seen in its relatively low per capita energy intake (Marie et al., 2021). About 90% of the households in the region use traditional biomass fuels as their main cooking energy source and about 10% use electricity from hydroelectric power (Asres, 2012). The inaccessibility and unaffordability of modern fuel and associated problems are more pronounced in the region (Getie and Degefa, 2019). Various interrelated economic and non-economic factors influence household cooking fuel choices in the ANRS and elsewhere in Ethiopia (Abebaw, 2007; Getie and Degefa, 2019; Wassie et al., 2021). Previous studies (Mekonnen and Köhlin, 2009; Gebreegziabher et al., 2012; Alem et al., 2016) mainly focused on analyzing the determinants of household cooking fuel choice of a single fuel type rather than jointly estimating the probability of choosing multiple fuel types simultaneously. However, households use multiple fuels for cooking activities as it provides users with energy security. A better understanding of factors that hinder the transition to modern fuels, understanding the drawbacks of traditional fuel consumption, and identifying factors influencing household cooking fuel choice will be critical for recommending energy development pathways for the country. Thus, this study aimed to examine the determinants of household cooking fuel choices and transitions among households residing in the Semien Mountains National Park (SMNP) and adjacent districts in Northwest Ethiopia.

## 2. Theoretical literature and conceptual framework

The theory of household fuel choice is founded on two widely used theories: the energy ladder and fuel stacking models (Masera et al., 2000). The energy ladder model views household fuel choices as a progression that corresponds to income growth, as well as a hierarchical order from traditional fuel to transitional fuel and eventually to modern fuels (Heltberg, 2005; Rahut et al., 2017; Giri and Goswami, 2018; Shallo et al., 2020). Further, the model described a linear and unidirectional progression of fuel adoption, claiming that moving up the ladder means abandoning the fuel at the lower level (Kowsari and Zerriffi, 2011). This model contradicts field research findings and is criticized by many studies for emphasizing income as a determinant of household fuel choice (Masera et al., 2000; Heltberg, 2004). Many recent studies have theorized household fuel choice from the perspective of fuel stacking. According to the fuel stacking model, energy choice and household transition do not always imply a stepwise transition from one fuel to another (Mensah and Adu, 2015). Instead, households combine various energy sources for multiple end-uses, and fuel choices are not mutually exclusive because households can use any combination of fuels at any time (Shallo et al., 2020).

A growing number of empirical studies have shown that fuel switching is not unidirectional and that people may return to traditional fuels after switching to modern fuels (Masera et al., 2000; Heltberg, 2004), and households may only partially switch to modern fuels (Kowsari and Zerriffi, 2011). According to the model, many factors besides household income, such as age, gender, education, family size, occupation, access to electricity, dwelling characteristics, availability of kitchen, off-farm activities, distance to the fuel sources, etc., influence household fuel choice (Kowsari and Zerriffi, 2011; Van Der Kroon et al., 2013; Rahut et al., 2014; Mottaleb et al., 2017, 2017; Danlami et al., 2018). The extent and dimension of how these factors influence household fuel choice sources vary from area to area and from one fuel source to another. This study hypothesizes that household fuel choice and use in the Semien Mountains and adjacent districts in northwest Ethiopia follows the fuel stacking model. Due to the availability of fuel stacking, it would be interesting to examine the choice of multiple energy sources for cooking.

## 3. Methods and materials

### *3.1. Description of the study area*

This study was conducted in the SMNP and adjacent districts, in Northwest Ethiopia. It is situated at geographical coordinates between 13°29′21″ to 13°29′40″ N and 37°51′36″ to 38°34′33″ E, with an area of 241,093 ha comprising a population of about 378,929. The SMNP is bordered by five administrative districts: Adiarkay, Beyeda, Debark, Jan-amora, and Telemet. The study site is characterized by alternating dry and wet seasons with a mean annual rainfall of between 1350 mm and 1600 mm. The mean annual temperature ranges from −2°C to 18°C (Hurni and Ludi, 2000). The altitude of the study area ranges from 1000 to 4600 m above sea level and is rich in natural resources and endemic and endangered biodiversity (Asrat et al., 2012). Mixed farming, government employee, forest and wild products collection, wage labor, and small business are the major source of livelihood (EWCA, 2015). The primary daily energy supply is derived from traditional energy sources, namely fuelwood, dung, charcoal, and electricity. Because of the burgeoning population, the study area has undergone rapid settlement over the last decades.

### *3.2. Study design, data sources, and methods of data collection*

The study employed a cross-sectional design, consisting of both descriptive and analytic. It's a descriptive study to characterize household energy consumption patterns in detail. Because it involved testing a priori hypothesis about household energy choice, it is also an analytic study design. The data was gathered from both primary and secondary sources. A pre-tested semi-structured questionnaire was used to obtain the primary data. The questionnaire was prepared first in English, then translated into the local language, Amharic, and back to English to check consistency and understandability. After the questionnaire was assessed by experts, it was pretested on 20 households that did not include it in the actual survey. The pretesting helped to ensure questionnaire clarity, the relevance of questions, and the time taken for an interview. Accordingly, appropriate amendments were made to the questionnaire before beginning the actual household surveys. The questionnaire consisted of demographic and socioeconomic variables, housing characteristics, fuel acquisition, and utilization patterns: sources of energy, fuel availability, type of fuel used for cooking, and issues related to household energy use patterns. Respondents were interviewed at their homes by trained data collectors. Before data collection, data collectors and supervisors were trained on data collection tools and how to obtain consent forms from respondents. The study considered household heads as the primary decision-maker concerning household energy use patterns. The authors follow ethical standards and principles throughout this study. The study households were contacted after getting an ethical approval letter from Addis Ababa University. Then, individual informed consent was obtained from potential participants, who were given the right to withdraw or refuse to answer specific questions at any time. The researcher, on the other hand, attempted to examine ethical issues throughout data collection to respect the right of participants.

### *3.3. Sampling techniques*

The study used a multi-stage sampling technique to select the study site, districts, kebeles, and sample households. Initially, the SMNP and adjacent districts were chosen purposively as a study site because (i) it is one of the most environmentally degraded areas in the ANRS, implying that a slight change in natural resources can have a far-reaching consequence on the livelihoods and associated ecosystem goods and services (ANRS and PaDPA, 2007) and (ii) it is an area where energy problems are intensive. In the second stage, out of five districts found in and around the Semien Mountains, Adiarkay and Debark *districts*[1] were purposively selected because they show significant variation concerning market access, infrastructure, proximity to forest resources, and availability of various energy sources (EWCA, 2015). In the third stage, six *kebeles*[2] were chosen purposively from the selected districts based on proximity to the source of fuel and market access, socioeconomic conditions, and availability of various energy sources. Finally, the households found in the selected kebeles during 2021 were identified and listed by the respective kebele administration. Then, the number of households selected from six kebeles was determined by dividing the sample size by the number of households in each kebele to get the representative sample households. Following that, 420 sample households were selected using a systematic random sampling technique, which was proportionally allocated to the household size of the six kebeles to ensure equal representation. Finally, the desired sample size was determined using Kothari (2004).

### *3.4. Methods of data analyses*

The data were entered into a statistical package for social science (SPSS V.20) and exported to STATA 14 for analysis. Descriptive statistics like frequency, percentage, graphs, mean, and standard deviations were employed to explain household socioeconomic, housing, and energy consumption patterns. A multivariate probit regression model was used to identify and analyze the factors that influence household cooking fuel choice decisions.

### *3.5. Econometric model*

This section describes our empirical framework-the discrete choice models employed to answer the research objective. Households in the study area depend on energy from various sources. When households are faced with energy options, they are more likely to choose a mix of fuels rather than rely on a single energy source. As a result, the choices to use different energy sources are correlated, and fuel choice decisions are inherently multivariate. Hence, the need to develop an empirical procedure that allows us to capture this interdependence. But, attempting univariate modeling would ignore useful information about interdependent and simultaneous fuel choice decisions (Rahut et al., 2017). Households may consider some combinations of fuel as complementary and others as competing. Failure to capture unobserved factors and inter-relationships

[1] District is the third level of the administrative division of Ethiopia after Zones.

[2] Kebele is the lowest administrative structure in Ethiopia.

among fuel choice decisions regarding various fuel choices will lead to biased and inefficient estimates (Tarekegn et al., 2017).

A shortcoming of most of the previous studies is that they do not consider the possible inter-relationships between the various energy sources. The empirical specification of choice decisions over the various sources of cooking energy can be modeled using either the multinomial logit (MNL) or multivariate probit (MVP) model. Previous studies have used the MNL model to deal with simultaneous binary decisions (Mekonnen and Köhlin, 2009; Rahut et al., 2014; Karimu, 2015; Alem et al., 2016). This model is appropriate when a household can choose only one outcome from a set of mutually exclusive alternatives. However, the problem with the MNL model is that it assumes the Independence of Irrelevant Alternative (s)[3] (IIA), which implies that the error terms of the choice equations are mutually exclusive and do not predict the joint interdependence of binary outcomes (Greene, 2003). However, the MVP model relaxes the property of the MNL. In the MVP model, the choices among various energy sources are not mutually exclusive since households accessing cooking fuel from more than one source may be correlated (Rahut et al., 2017).

In this study, we used the MVP model, which simultaneously estimates the influence of the set of explanatory variables on each of the various fuel choices, while allowing the unobserved/or unmeasured factors (error terms) to be freely correlated (Greene, 2003; Belderbos et al., 2004). Some of these energy sources can be used simultaneously as complements to other sources (positive correlation), while others can be used as substitutes (negative correlation) (Belderbos et al., 2004). As shown by Cappellari and Jenkins (2003), if a household $i$ is faced with $m$ different choices, then the multivariate probit model can be constructed as follows:

$$Y^*_{im} = X_{im}\,\beta'_m + \varepsilon_{im},\ m = Y_1, Y_2,\ Y_3,\ Y_4\ , Y_5 \text{ and} \quad (1)$$

$$Y_{im} = \begin{cases} 1\ if\ y^*_{im} > 0 \\ 0\ otherwise \end{cases} \quad (2)$$

where $m = Y_1, Y_2,\ Y_3,\ Y_4\ , Y_5$ denotes the dependent variables, i.e., five cooking fuels available

In Eq. (1), the assumption is that a rational i$^{th}$ household has a latent variable, $Y^*_{im}$, which captures the unobserved preferences associated with the m$^{th}$ choice of cooking fuels. This latent variable is assumed to be a linear combination of observed characteristics ($X_{im}$), including socioeconomic, environmental, and institutional characteristics that affect the choice of m$^{th}$ cooking fuel, as well as unobserved characteristics captured by the stochastic error term $\varepsilon_{im}$. The vector of unknown coefficients/parameters ($\beta'_m$) are estimated using simulated maximum likelihood. Given the latent nature of $Y^*_{im}$, the estimations are based on observable binary discrete variables $Y_{im}$, which indicates whether or not a household undertook a particular cooking fuel.

If the choice of a particular cooking fuel is independent of whether or not a household uses another fuel (i.e., if the error terms, $\varepsilon_{im}$, are independent and identically distributed (IID) with a standard normal distribution), then Eqs. (1) and (2) specify univariate probit models, where information on households' choice of one cooking fuel does not alter the prediction of the probability that they will choose another cooking fuel. However, if the choice of several cooking fuels is possible, a more realistic specification is to assume that the error terms in Eq. (1) jointly follow a multivariate normal (MVN) distribution, with zero conditional mean and variance normalized to unity, where $\varepsilon_{im} \sim$ MVN (0, Σ) and the covariance matrix Σ is given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{EC} & \rho_{EF} & \rho_{ED} & \rho_{ER} \\ \rho_{CE} & 1 & \rho_{CF} & \rho_{CD} & \rho_{CR} \\ \rho_{FE} & \rho_{FC} & 1 & \rho_{FD} & \rho_{FR} \\ \rho_{DE} & \rho_{DC} & \rho_{DF} & 1 & \rho_{DR} \\ \rho_{RE} & \rho_{RC} & \rho_{RF} & \rho_{RD} & 1 \end{bmatrix} \quad (3)$$

Of particular interest are the off-diagonal elements in the covariance matrix, $\rho_{mj}$, which represents the unobserved correlation between the stochastic component of the m$^{th}$ and j$^{th}$ type of cooking fuel choices. This assumption means that Eq. (2) gives the MVP model that jointly represents decisions to choose a particular cooking fuel. This specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative cooking fuels.

### *3.6. Description of variables and hypothesis*

During the field survey, households reported five sources of cooking energy, including fuelwood, dung, crop residues, charcoal, and electricity. Some of these energy sources can be used as complements with others, while others may be used as substitutes. Households make five energy choice decisions, as each activity provides them with a certain threshold level of utility. Each choice of energy cannot be estimated separately as a single probit model because of the interdependence of error terms (Rahut et al., 2017). As shown in Eq. (1), the dependent variable, cooking energy choice, is based on five energy options. For each of the cooking energy sources, a discrete binary variable takes the value 1 if it is chosen or 0 otherwise.

The choice of independent variables that were assumed to influence household energy choices was determined based on a review of theoretical literature and previous research findings (Van Der Kroon et al., 2013; Hou et al., 2017; Rahut et al., 2017; Danlami et al., 2018; Wassie et al., 2021). Table 1 illustrates the variables hypothesized to determine household cooking fuel choices. Before entering the predictors into the MVP model for further analysis, tests for the existence of multicollinearity problems were conducted using the Variance Inflation Factor (VIF) through STATA version 14 for continuous predictors and correlation matrix analysis for non-continuous explanatory variables. Accordingly, the results of multicollinearity tests showed that there were no multicollinearity problems.

## 4. Results and discussion

### *4.1. Descriptive statistics*

A total of 420 households were sampled for the survey, but only 403 were analyzed, resulting in a 96% response rate (Table 2). The results revealed that males headed 75% of the sampled households. The mean age of the household head was 45.2 years, with 24 and 71 being the minimum and maximum, respectively, and household heads' average years of schooling were 4.6 years. The average household size was about 5.5 persons, which is larger than the national average (4.6) (CSA, 2016) and regional average (4.6) (CSA, 2013). The average yearly income of the sampled households was estimated at Birr 18,123. In addition, 65% of the households in the sample engaged in off-farm activities.

Regarding occupational status, 75% of household heads work in agriculture. Descriptive statistics show that 73% of sampled households live in a modern houses. Additionally, 38% and 63% lacked separate kitchen facilities and access to electricity, respectively. Moreover, about 27% of the total 403 households were unaware of the health effects of biomass fuel burning. Furthermore, on average, households travel 130 min and 69 min to the nearby market and forest source, respectively, which probably determines the type of fuel used by households.

[3] Independence of irrelevant alternatives states that the odds of choice do not depend on irrelevant alternatives.

**Table 1**
Description and measurement of variables and hypothesis.

| Variables | Category | Measurement | Expected effect on cooking fuel choice | | | | |
|---|---|---|---|---|---|---|---|
| | | | Elec. | Char. | FW | Du. | CR |
| Gender of household head | Dummy | 1 if female, 0 male | + | + | + | − | − |
| Age of household head | Continuous | Age in years | +/- | + | − | − | − |
| Education of household head | Continuous | Years of schooling | + | + | − | − | − |
| Household size | Continuous | In number | − | − | + | + | + |
| Occupation of household head | Dummy | 1 if farming, 0 salaried | − | − | + | + | + |
| Annual income | Continuous | In Ethiopian Birr | + | + | +/- | − | − |
| Participation in off-farm activity | Dummy | 1 if participated, 0 otherwise | + | + | + | − | − |
| Type of House | Dummy | 1 if corrugated, 0 thatched | + | + | +/- | − | − |
| Availability of separate kitchen | Dummy | 1 if separate, 0 otherwise | + | + | +/- | +/- | − |
| Access to electricity | Dummy | 1 if access, 0 otherwise | + | + | − | − | − |
| Distance to marketDistance to the forest | ContinuousContinuous | Walking distance in minutesWalking distance in minutes | -- | -+ | ++ | +- | +- |

Elec. - Electricity; Char. - Charcoal, FW - Fuelwood; Dun. - Dung; CR - Crop residue.

**Table 2**
Summary statistics of variables used in the study.

| Categorical Variables | Responses | Frequency | Percentage |
|---|---|---|---|
| Gender of the household head | Female | 102 | 25 |
| | Male | 301 | 75 |
| Occupational of the household head | Farming | 301 | 75 |
| | Paid employment | 102 | 25 |
| Access to electricity | Yes | 149 | 37 |
| | No | 254 | 63 |
| Type of house | Modern | 296 | 73 |
| | Traditional | 107 | 27 |
| Availability of separate kitchen | Yes | 251 | 62 |
| | No | 152 | 38 |
| Awareness about the harmful effect of biomass energy sources | Yes | 296 | 73 |
| | No | 107 | 27 |
| Participation in off-farm activities | Yes | 262 | 65 |
| | No | 141 | 35 |

| Continuous Variables | Observations | Mean | Std. Dev. |
|---|---|---|---|
| Age of the household head (Years) | 403 | 45.2 | 11.4 |
| Educational level (Year of schooling) | 403 | 4.6 | 3.4 |
| Household size (Number) | 403 | 5.5 | 1.8 |
| Annual Income (Birr) | 403 | 18,123 | 9965 |
| Distance to the nearest market (Minutes) | 403403403 | 13016869 | 888937 |
| Time spent to collect fuelwood (Minutes) | | | |
| Distance to the forest (Minutes) | | | |

Source: Field Survey (2021).

**Table 3**
Proportion of households using different sources of energy for domestic use (in%).

| Type of fuel | Frequency | Percentage (%) |
|---|---|---|
| Electricity | 68 | 16.9 |
| Charcoal | 131 | 32.5 |
| Fuelwood | 352 | 87.3 |
| Dung | 330 | 81.9 |
| Crop residue | 136 | 33.8 |

Source: Field survey (2021).

**Table 4**
The proportion of Households by fuelwood collection sources.

| Fuelwood collection sources | Frequency | Percentage (%) |
|---|---|---|
| On-farm | 134 | 33.2 |
| State and community forest | 218 | 54.1 |
| Purchasing | 51 | 12.7 |

Source: Field survey (2021).

#### *4.1.1. Patterns and sources of household energy use*

The results revealed that 87% of the households predominantly used fuelwood, followed by cattle dung (82%) and crop residue (34%). In contrast, only 33% and 17% of the sampled households used charcoal and electricity as the main baking and cooking energy sources (Table 3). The prevalence of poverty influences the increased use of fuelwood and dung; thus, they cannot afford to invest in modern energy sources, such as electricity.

Since biomass fuel, particularly fuelwood, was predominantly used by sampled households in the study area, it may imply easy availability and affordability of biomass (Table 4). There are various sources from which a household can obtain fuelwood. Among the fuelwood users, 33% collected from their farm, 54% from off-farm (community and state forests), and the remaining 13% reported purchasing from the market. According to the study discussants, rapid land use and forest cover changes have reduced biomass supply. This has strained state and community forests and resulted in fuelwood scarcity in the area.

Owing to the government ban on fuelwood collection from state forests in the study area, the percentage of households using cattle dung, crop residue, and communal land has continued to rise. Dried dung was available for free since livestock rearing was common. The results revealed that own livestock was a significant source of cattle

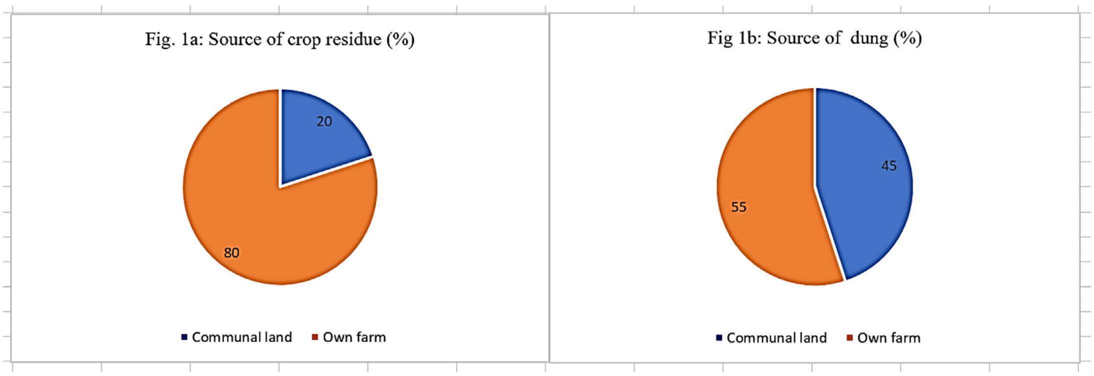
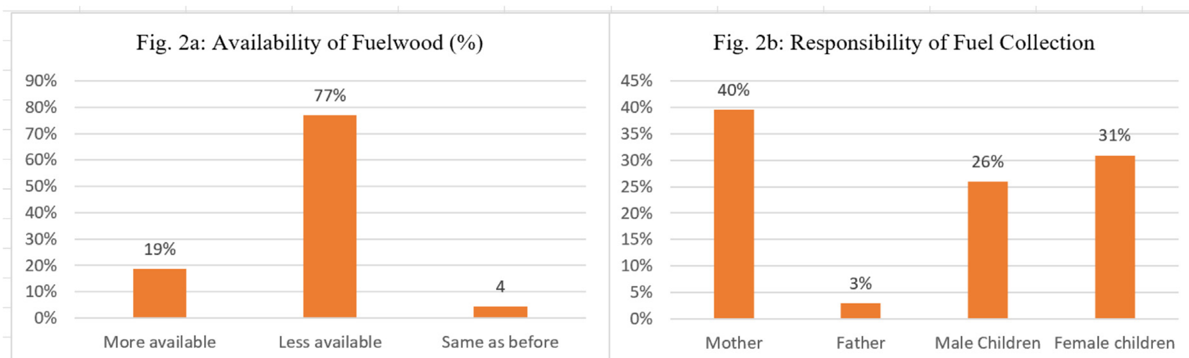



**Fig. 1.** a. Source of crop residue (%), b. Source of dung (%), Source: Field survey (2021)




Source: Field survey (2021)

**Fig. 2.** a. Availabilty of Fuelwood (%), b. Responsibilty of Fuel Collection, Source: Field survey (2021)

dung (55%), and 45% was collected from other farms (Fig. 1b). Similarly, crop residues of wheat, barley, and sorghum were commonly used as fuel by the sampled households. In the same vein, about 80% of the households that use crop residues depend on their farm and 20% of them are collected from other farms (Fig. 1a).

Moreover, about 77% of the sampled households perceived that fuelwood availability had decreased over time (Fig. 2a). According to key informants, this was primarily due to forest loss due to the increased human population. The decline in fuelwood availability indicates the over-exploitation of forests and the increased time spent by fuelwood collectors. The results revealed that fuelwood collectors have to walk (round trip) for a minimum of 60 min and a maximum of 360 min to collect headloads of fuelwood, with an average of about 168 min (Table 2). On the other hand, both male and female members of households are involved in collecting fuelwood. The results demonstrated that women are the most likely (40%) to collect fuelwood, followed by girls (31%) and boys (27%) (Fig. 2b).

### *4.2. Econometric analyses*

#### *4.2.1. Determinants of household fuel choices*

In this study, 12 predictors were hypothesized to influence household cooking fuel choice (Table 2). The results showed the effect of each predictor on each dependent variable category, suggesting that one predictor may have a significant and positive or negative effect on one or more or none of the variables. The estimated correlation coefficients were statistically significant in six of the ten pair cases, with two coefficients having positive and the remaining four having negative signs (Table 5). The result supports the hypothesis that error terms of multiple fuel choice decisions are correlated. As a result, cooking fuel choices within a single household were mutually inclusive, allowing us to apply the MVP model to estimate household fuel choices. The likelihood ratio test [$\chi^2$ (10) = 61.74, Prob > $\chi^2$ = 0.000] of the null hypothesis that the covariance of the error terms across equations is not correlated is also rejected. Crop residue and fuelwood, as well as charcoal and electricity, were significantly and positively associated, implying that these fuels are primarily considered as complements by households. On the other hand, dung and fuelwood, as well as fuelwood and electricity, were significantly and negatively associated, suggesting these energy sources were used as substitutes for households (Table 5).

The MVP model fits the data reasonably well as the Wald test [$\chi^2$ (60) = 294.94; Prob > $\chi^2$=0.0000] of the null hypothesis that all regression coefficients in each equation were jointly equal to zero was rejected, suggesting that the variables included in the model explain significant portions of the variations in the dependent variables (Table 6). As evident from the MVP regression results, the estimated coefficient of the age of the household head was negative and statistically significant for the choice of electricity ($P < 0.01$) but positive and significant for the choice of dung ($P < 0.1$). This suggests that the probability of choosing dung increases as the age of the household head increases. This might be because cattle dung is readily available. Besides, older household heads are known to resist change, often adhere to social norms, and thus rely on biomass. This corresponds to the findings of Mekonnen and Köhlin (2009), Baiyegunhi and Hassan (2014), Rahut et al. (2016), Giri and Goswami (2018), Paudel et al. (2018), Rahut et al. (2020), and Mottaleb (2021). But, the probability of choosing electricity decreases as the age of the household head increases. This might be associated with the perception that older people feel that electricity is not safe to use and not readily available and affordable like biomass fuels. This finding is in accord with Abdul-Wakeel Karakara and Dasmani's (2019) finding. However, it contradicts the findings of Gebreegziabher et al. (2012), Guta (2012), Rahut et al. (2017), and Mottaleb (2021), who found a positive relationship between age and the choice of modern energy sources. This is because of the household heads' life cycle effect, i.e. the higher

**Table 5**
Correlation coefficients between energy sources used by households.

| Parameter | Correlation Coefficient | Standard error | Z-value |
|---|---|---|---|
| Charcoal and Electricity | 0.2534 | 0.1505 | 1.684* |
| Fuelwood and Electricity | −0.2811 | 0.1592 | −1.770* |
| Dung and Electricity | 0.1157 | 0.1467 | 0.790 |
| Crop residue and Electricity | 0.1401 | 0.1507 | 0.930 |
| Fuelwood and Charcoal | −0.2898 | 0.1017 | −2.850*** |
| Dung and Charcoal | −0.0888 | 0.1284 | −0.692 |
| Crop residue and Charcoal | −0.0440 | 0.1120 | −0.339 |
| Dung and Fuelwood | −0.7600 | 0.1520 | −4.990* |
| Crop residue and Fuelwood | 0.2720 | 0.1030 | 2.640*** |
| Crop residue and Dung | −0.2585 | 0.1131 | −2.280** |

Likelihood ratio test of rho21=rho31=rho41=rho51=rho32=rho=42=rho43=rho=53=rho54=0; $\chi^2$ (10) = 60.05, Prob > $\chi^2$= 0.0000; *, **, and *** refer to significant at 10%, 5%, and 1% level, respectively.
Source: Authors' computation.

**Table 6**
Results of Multivariate probit estimation of household cooking fuel choice.

| Explanatory Variables | Dependent Variables (Choice of Fuel) | | | | |
|---|---|---|---|---|---|
| | Electricity Coef. (SE) | Charcoal Coef. (SE) | Fuelwood Coef. (SE) | Dung Coef. (SE) | Crop residue Coef. (SE) |
| Age of the household head | −0.167 (0.087)*** | −0.008 (0.008) | 0.003 (0.009) | 0.019(0.011)* | 0.003(0.008) |
| Gender of household head | 4.779 (2.314)** | 0.247 (0.177) | −0.578 (0.197)*** | −0.286 (0.226) | −0.312(0.192)* |
| Household size | −0.947 (0.526)* | 0.102 (0.042)*** | 0.080 (0.048)* | 0.031 (0.055) | 0.217(0.045)*** |
| Education of the household head | 0.068 (0.026)*** | 0.007 (0.024) | −0.018 (0.029) | −0.061 (0.031)** | −0.057(0.031)*** |
| Occupation of the household head | −1.969(1.338)*** | −0.579(0.215)*** | −0.202(0.273) | 1.137(0.267)*** | −0.270(0.235) |
| Log_household income | 5.693 (3.138)* | 0.472 (0.242)** | −0.582 (0.274)** | −0.057 (0.327) | −0.139 (0.067)*** |
| Distance to the market | −0.075 (0.037)** | 0.001 (0.001) | 0.002(0.001)* | 0.003 (0.001)* | −0.002(0.001)* |
| Type of house | 4.063 (6.580) | 0.169 (0.219)** | 0.356 (0.246) | −0.880 (0.338)*** | −0.913(0.214)*** |
| Participation in Off-farm | 2.380(1.262)* | 0.003(0.163) | −0.184(0.194) | −0.367(0.229)* | −0.191(0.155) |
| Access to electricity | 6.744(3.427)** | 1.100(0.207)*** | 0.157(0.247) | −1.108(0.278)*** | −1.384(0.226)*** |
| Availability of kitchen | 2.314(0.861)*** | −0.111(0.218) | −0.061(0.244) | −0.526(0.333)* | −0.376(0.204)* |
| Distance to forest | −0.040(0.079) | 0.002(0.002) | 0.051(0.030)* | −0.005(0.002)** | −0.004(0.002)** |
| Number of obs = 403 | | | | | |
| Log likelihood = −605.49 | | | | | |
| Wald $\chi^2$(60) = 294.94 | | | | | |
| Prob > chi2 = 0.0000 | | | | | |

Values in the parenthesis are standard errors.
*, **, *** refer to significant at 10%, 5%, and 1% levels, respectively; Source: Field survey (2021).

a household head moves up in their life cycle, the wealthier they become, and the more likely to invest in modern fuels (Van Der Kroon et al., 2013). Also, Rahut et al. (2020) concluded that the elderly need more convenient fuel sources because they are not as strong as those who have to travel a long distance to collect biomass fuels.

Besides, the estimated coefficient of female-headed households was positive and significant for the choice of electricity ($P < 0.05$) but negative and significant for the choice of fuelwood ($P < 0.01$) and crop residue ($P < 0.1$). This implies that the probability of choosing electricity is more likely when the household is female-headed. This may be attributed to the fact that females are often responsible for cooking and are more concerned about the hazardous health effects of biomass fuels and are, thus, less inclined to use biomass fuels. This finding is consistent with the findings of Rahut et al. (2014), Behera et al. (2015), Mensah and Adu (2015), and Mottaleb (2021). But, it contradicts the findings of Mekonnen and Köhlin (2009) and Abdul-Wakeel Karakara and Dasmani (2019), who found that female-headed households may not have the economic strength to use electricity and are more likely to use biomass fuels.

Again, the result shows that the coefficient of household size is negative and statistically significant for the choice of electricity ($P < 0.1$) but positive and significant for the choice of fuelwood ($P < 0.1$) and crop residue ($P < 0.1$). Increasing family sizes implies abundant labor for fuel collection, limiting the need to move to modern fuels. Besides, a large household requires more energy and thus chooses biomass energy sources. This finding is concurrent with past studies conducted in Ethiopia (Guta, 2012) and other developing countries Giri and Goswami (2018); Muller and Yan (2018); Paudel et al. (2018). However, this finding contradicts the findings of Pandey and Chaubal (2011) and Twumasi et al. (2020), who reported that a negative association exists between household size and the choice of electricity.

Interestingly, education is an important policy tool to raise households' awareness about the benefits of modern energy sources and the risk of biomass fuels. Our result indicates that the estimated coefficient of the household head's years of schooling showed a positive and statistically significant effect on the choice of electricity ($P < 0.01$), but it was negative and significant with the choice of dung ($P < 0.05$) and crop residue ($P < 0.01$). This implies that as the household heads years of schooling increase, so does the likelihood of using electricity. This was most likely explained by the increasing opportunity costs of fuel collection time at higher levels of education and the increased level of awareness of the adverse health and environmental effects of using biomass fuels. This finding is consistent with results from past studies conducted in Ethiopia by Mekonnen and Köhlin (2009), Gebreegziabher et al. (2012), and Guta (2012) and other developing countries (Lay et al., 2013; Rahut et al., 2014; Behera et al., 2015; Imran et al., 2019; Mottaleb (2021)). However, this finding contradicts the finding of Sehjpal et al. (2014), who found that education does not directly impact household sources of energy choice. The argument is that education may indirectly influence the use of modern energy if only it leads to employment, which, in turn, may increase income (Hou et al., 2017). But, whether education influences the use of modern energy directly or indirectly, the consensus is that education plays a vital role in determining household energy choices.

In addition, the type of occupation of a household head may affect the cooking fuel choice. The results revealed that the effect of household heads engaged in farming is negative and significant for the choice of electricity ($P < 0.01$) and charcoal ($P < 0.01$) but positive and significant for the choice of dung ($P < 0.01$). It implies that household heads involved in farming are more likely to use biomass than electricity. However, household heads employed in the public sector are more likely to choose electricity or charcoal. This might be because the opportunity cost of collecting biomass fuels is high for public sector employees, corroborating past research findings (Pandey and Chaubal, 2011; Rahut et al., 2016).

Moreover, household income is assumed to be the main driver when choosing the type of energy. Although income plays an important role in cooking fuel choice, many still dispute it. According to Akpalu et al. (2011), income increase has not shifted households to modern fuel, while Kowsari and Zerriffi (2011) explained households use a mix of energy sources rather than one particular source of energy. The results revealed that the estimated coefficient of income was positive and significant for the choice of electricity ($P < 0.1$) and charcoal ($P < 0.05$), but it was negative and significant for the choice of fuelwood ($p < 0.05$) and crop residue ($P < 0.01$). This suggests that higher-income households are more likely to invest in and use electricity. One possible explanation is that household purchasing power improves as income increases, making electricity more affordable. This finding concurs with those of Behera et al. (2015), Mensah and Adu (2015), Alem et al. (2016), and Imran et al. (2019).

Another predictor variable influencing household energy choice was the distance from the market. The coefficient of the distance to the market is negative and significantly associated with the household choice of electricity ($P < 0.01$) and positive and associated considerably with fuelwood ($P < 0.1$) and dung ($P < 0.1$). This suggests that households living further away from the market are more likely to use biomass and less likely to use electricity. There is probably a greater likelihood that modern fuels like electricity are available around the main market center. The findings of this study are consistent with those of previous studies conducted in developing countries by Van Der Kroon et al. (2013), Behera et al. (2015), Rahut et al. (2017), and Imran et al. (2019).

Housing type can be viewed as an indicator of household living conditions, affecting household energy choice. A variety of housing attributes can be considered in the literature. In this study, the material used to construct the roof of the house are used to classify it into two categories: modern (corrugated roofs) and traditional (thatched roofs). In the case of a household living in a modern house, the estimated coefficient of charcoal is positive and statistically significant ($p < 0.05$), but it is negative and statistically significant for dung ($P < 0.01$) and crop residue ($P < 0.01$). This implies that households living in modern houses have a higher propensity to choose and use charcoal, which is in line with the finding of Baiyegunhi and Hassan (2014).

Another predictor variable that affects household energy choice is household access to electricity. Access to electricity is seen as an essential input for micro and small enterprises, which are the main contributors to job creation and improving the livelihoods of society. The results showed that the coefficient for access to electricity was positive and statistically significant for the choice of electricity ($P < 0.05$) and charcoal ($P < 0.01$), but it was negative and significant for the choice of dung ($P < 0.01$) and crop residue ($P < 0.01$). This implies that households with access to electricity are more likely to use electricity relative to households without access to electricity. This is most likely because using electricity is linked to an improvement in the standard of living and availability. This finding is in line with results reported from studies conducted in Ethiopia (Daniel, 2020; Wassie et al., 2021) and other developing countries (Karimu, 2015; Rahut et al., 2016; Lokonon, 2020), which found a positive association between access to electricity and electricity use. However, this finding is in contrast with the finding of Trac (2011), who found that electricity availability within a household does not necessarily mean the use of modern energy sources for all energy consumption. For example, some meals may still be cooked using biomass fuels because of social norms, which agrees with the fuel stacking theory.

Participation in off-farm activities was also a factor that influenced the choice of source of energy. The estimated coefficient for a household participating in off-farm activities was positive and statistically significant for the choice of electricity ($P < 0.1$). In contrast, it was negative and significant for the use of dung ($P < 0.1$). This indicates that when a household head is engaged in off-farm income, the probability of choosing electricity is enhanced since income from off-farm activities helps the household to earn supplementary income to diversify and invest in various modern energy alternatives. This finding supports the findings of Ma et al. (2019) and Lin and Zhao (2021), who indicated a positive association between off-farm income and the probability of households using electricity.

Moreover, the availability of a separate kitchen was identified as an important factor influencing household sources of energy choice. The estimated coefficient for the availability of a separate kitchen is a positive and statistically significant effect on the choice of charcoal ($P < 0.01$). At the same time, it is negative and significant for the choice of dung ($P < 0.05$) and crop residue ($P < 0.01$). This implies that households with no separate kitchens are more likely to choose biomass for cooking. A possible explanation is that households with separate kitchens are more aware of the harmful effects of IAP caused by burning biomass fuels. This finding corroborates the findings of Pundo and Fraser (2006), Paudel et al. (2018), and Daniel (2020).

Furthermore, distance from the forest influences a household's fuel choice decisions. The results showed that the coefficient of the distance to the forest had a negative and significant effect on the choice of dung ($P < 0.05$) and crop residue ($P < 0.05$), but it was a positive and significant effect on the choice of fuelwood ($P < 0.1$). This suggests that households are less likely to switch to modern fuels when they are closer to the forest source. The possible reason might be the opportunity cost of collecting fuelwood is lower, which is in line with the findings of Joshi & Bohara (2017).

## 5. Conclusions and policy implications

This study examined household energy utilization patterns, and factors affecting cooking fuel choice in the SMNP and adjacent districts using data from 420 randomly selected households. Since this study was cross-sectional and we were unable to examine how the variables changed over time, the findings should be treated with caution. Results indicate that households' energy utilization pattern is skewed towards biomass fuels, particularly fuelwood. The results also showed that fuelwoods are not inferior, as opposed to the energy-ladder hypothesis, and households continue to rely mainly on these fuels for cooking. However, although fuelwood is a renewable fuel source, over-extraction can lead to deforestation and environmental degradation and thus can significantly negatively impact sustainable development. Besides, our findings revealed that households choose multiple fuels for domestic chores for various reasons, including that entire reliance on single energy may be subject to price fluctuations and unreliable supply. Thus, households tend to follow a multiple fuel use strategy as their income, education, and settlement patterns improve. Empirical results of the MVP model further reveal that a mix of factors, including age, gender, household size, education, income, access to electricity, off-farm activities, distance to forest, access to market, and type of house considerably govern a household's choice of cooking fuel and the extent of dependency on it.

The study has substantial policy implications that should be considered in policy design. First, this study's findings reveal that education has positive returns on people's energy choice behavior. Consequently, raising public awareness of the negative impacts of an over-reliance on biomass on both human health and the environment. These social norms, as a result, encourage the use of modern fuels. Besides, a slow transition to electricity is evident because only about 17% of grid-connected households use electricity for domestic use. Therefore, the study strongly recommends investing in overall livelihood improvement programs, human capital, and improving the provision of infrastructure to encourage the use of electricity for cooking. Finally, switching to a modern energy source will take time because biomass is still the most common energy source for domestic chores. Thus, policymakers should encourage households to use fuel-efficient cooking stoves to increase biomass cooking efficiency.

## Declaration of Competing Interest

The authors declare that they have no conflict of interest.

## Data availability

Data will be made available on request.

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