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Rural Households' Behaviour towards Modern Energy Technology Adoption Choices in East Gojjam Zone of Ethiopia: A Multivariate Probit Regression Analysis

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Abstract: Many rural communities in developing countries continue to rely on biomass for energy, which has a negative impact on their socioeconomic development. Following the United Nation's Sustainable Development Goals—zero hunger and affordable modern/clean energy for all—many developing nations are now taking substantial initiatives to enhance rural clean energy access. As a result, this research explored rural household behaviors toward adopting alternative modern energy sources in East Gojjam Zone, Ethiopia. In an attempt to do so, 317 rural households were surveyed, and the data were analyzed using the multivariate probit (MVP) model. According to the MVP model results, education level, land size, credit availability, awareness, distance to market, and early neighbor adopters have positive effects on the choice of solar energy sources, whereas livestock holding, household income, extension contact, distance to biomass sources, and training access have negative effects. Besides this, the estimated MVP for improved cook stoves is positively influenced by livestock holding, income, extension contact, distance to biomass sources, awareness, training access, and early adopters. In contrast, education level, household size, agricultural experience, land size, access

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The author of this essay, Fasika Chekol Mekonnen, holds an MSc in Economics from Addis Ababa University, with a specialization in Economic Policy Analysis. The author is currently working as a lecturer in Economics at Debre Markos University. The author is interested in conducting research on the areas of consumer preference, technology adoption, production efficiency, agricultural marketing, renewable energy sources, nonfarm business for women rural empowerment, employee training, and business networking alliance strategy for firm performance.

PUBLIC INTEREST STATEMENT

Access to clean energy sources has transformed into a strategic commodity for acknowledging a greater standard of living and becoming a factor in a country's socioeconomic development. Clean energy, for example, can help people get out of poverty, improve their health, gender equality, and environmental sustainability. However, any uncertainty about its availability may adversely impact the economy's functioning, particularly in developing countries. As a result, this study investigates the factors that influence rural household energy choices for solar, ICS, and biogas technologies. According to the findings, the frequency of extension contact, access to credit, distance to market, access to training, and awareness are all significant factors in households' decisions about clean energy options. As a result, in order to improve technology adoption, all significant factors must be addressed.

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to credit, and distance to market all have a negative influence. Moreover, extension contact, distance to biomass sources, and availability of training have a positive impact on the choice of biogas energy sources, whereas credit access, awareness, distance to market, and early adopters have a negative effect. Regarding the propensity to use modern energy sources in the study area, infrastructural development was identified as critical.

Subjects: Sociology; Economics; Environmental Economics; Finance

Keywords: household; modern energy choice; clean energy; biomass

1. Introduction

Access to modern energy is becoming extremely important for human well-being and socioeconomic advancement (Biratu, 2016; Gielen et al., 2019; Yonas et al., 2013). To lift people out of poverty, enhance people's healthcare, encourage gender equality, and improve natural resource management, clean, efficient, economical, and dependable energy services are necessary (International Energy Agency, 2020; Pachauri et al., 2012; Sapkota et al., 2014). Energy has become known as a "strategic commodity," and any uncertainty about its supply might undermine the economy's functioning, especially in developing countries (Sen & Ganguly, 2017). Inconsistent energy supply not only places a financial burden on households; it also leads to welfare losses and air pollution (Bruce et al, 2015).

However, rural developing-country communities lack access to modern energy, at least for basic cooking and lighting, forcing them to rely on biomass energy. Domestic energy consumption in rural and urban Ethiopia is mostly fulfilled by woody biomass, agricultural residue, and animal dung (Anteneh, 2019). Biomass provides for significantly more than 90% of the energy utilized in the country in its various forms (International Energy Agency, 2020). In rural households, for example, wood and charcoal were used for cooking, while kerosene lamps and dry cell batteries were used for lighting (Abate, 2016; Ahmar et al., 2022; Jeuland & Pattanayak, 2012; Tucho & Nonhebel, 2017). Due to this, millions of hectares of forest are lost each year in Ethiopia due to fuel wood gathering. As a result, fuel wood scarcity and rising firewood costs have become common, and crop residue and animal dung are being substituted for fuel wood. This substitution depletes valuable soil nutrients and thus soil fertility, contributing to the agricultural production slowdown (Anteneh, 2019). Ethiopia's population, on the other hand, is rapidly growing, putting a strain on limited food resources and the majority of the population subsists on subsistence agriculture (Admassie & Abebaw, 2021).

Since traditional energy sources are economically inefficient, the Ethiopian government has been working hard in recent times, through collaboration with the United Nations Development Program (UNDP) and the Netherlands Development Organization (SNV), to increase the use of modern and clean energy sources in rural areas (International Energy Agency, 2020). Furthermore, the Federal Government of Ethiopia encourages the adoption of solar photovoltaic (PV) systems, improved cookstoves, and residential biogas systems. Furthermore, because they may be transformed into multiple energy forms, biomass (converted to biogas) and solar energy sources are promising for satisfying demand. Biogas may be used directly to provide cooking heat and may be transformed into energy for a variety of uses. Solar energy may also be transformed into electricity within a photovoltaic cell (PVC) and concentrated to create cooking heat (concentrated solar cooker: CSC) and electricity via a concentrated solar power (CSP) system (Tucho & Nonhebel, 2017). As a result, installing alternative modern energy technologies such as better cook stoves, biogas, and solar energy sources would be crucial for changing Ethiopia's energy consumption pattern by lowering spending on fuel-wood, deforestation, and environmental damage.

However, in poor rural economies, households either rely on traditional energy sources or do not use modern cooking and lighting (Arthur et al., 2011; Biratu, 2016). Overall, it is uncertain that the

United Nations' Sustainable Development Goals (SDGs) (SDGs 7)—clean, modern, and affordable energy for all—will be met by 2030. (Chirambo, 2018). The use of biomass for cooking and lighting contributes to an excessive amount of biomass extraction and consumption. Inefficient biomass utilization has been connected to an increase in child labor, deforestation, indoor air pollution that is harmful to users' health, and a drop in agricultural productivity (Biratu, 2016; Bruce et al., 2015; Mekuria, 2016).

Ethiopia, and particularly the East Gojjam zone, suffers from acute energy poverty. Most rural households do not use modern energy sources for cooking and lighting. They are out of reach for the majority of households and lack the basic needs of energy resources. As a result, the use of solid biomass with traditional cooking stoves is likely to continue. If households' energy choices do not move toward renewable energy sources, the energy sector's long-standing cyclical debt would be devastating for the country, which is already in financial distress. Furthermore, attempts to accept and utilize new energy sources are vital.

Despite the importance of modern energy sources in most developing nations, large-scale empirical research on household behavior toward the adoption of modern energy sources is lacking. First, empirical studies are dispersed and mostly qualitative. Second, these studies do not include rigorous statistical analysis of household adoption of modern energy technologies. As a result, this study attempted to fill these research gaps. To encourage the adoption of modern energy sources, it is necessary to identify the factors that make them appealing to households. Therefore, the objectives of this study are to explore the determinants of rural household behaviors toward the adoption of alternative modern energy options in East Gojjam Zone, Ethiopia.

2. Literature review

Rural households choose multiple energy sources to maximize their benefit from energy demand for cooking and lighting. However, a variety of factors influence households' decisions on which energy sources to consume for lighting and cooking. Numerous studies have been undertaken across nations that determine the factors of household energy decisions, with mixed results.

Scholars such as (Ahmar et al., 2022) in Pakistan; Karanja and Gasparatos (Karanja & Gasparatos, 2020) in Kenya; (Yu & Luo, 2022) in China; (Zeng et al., 2022) in Hubei; (Conley & Udry, 2010) in Ghana; (Wang & Yu, 2017) in Taiwan; (Benjamin, 2013) in Nigeria; and (Van der Kroon et al., 2013) in the Netherlands examined the determinants of energy choices at the household level. Based on the empirical findings of these studies, sex, education, household size, livestock holding size, and credit access, income, land size, extension visit, and distance to woodland, farming experience, observational and interpersonal learning, word of mouth from neighbors, and the efficiency of extension services are the major factors that influence a household's energy choice decision. Unfortunately, just a little research has been conducted in Ethiopia. Authors such as (Shallo & Sime, 2019), (Wassie et al., 2021), (Bahta & Berhe, 2020), Guta (Guta, 2020), (Shallo et al., 2020), and (Kelebe et al., 2017) investigated the factors that influence household energy demand. The empirical findings also reveal that age, education, household size, land size, distance to market, credit accessibility, follow-up and support, and distance to woods impact households' energy choices.

Table 1 is an overview of the empirical findings of past studies on the factors affecting household energy choice decisions. The key elements influencing household energy choice, as shown in the Table 1 below, may be classified as infrastructure related and socioeconomic features. Access to financing, distance to the market where energy technologies are accessible, and frequency of extension contact are all infrastructure-related characteristics. Age, education, family head income, livestock holding size, and the existence of early adopter neighborhoods are all socio-economic factors. Despite this, all of the empirical literature studied was either focused on traditional energy sources (such as firewood, charcoal, dung cake, and so on) or a combination of some traditional and some contemporary (electrical, dry cell battery, solar, and biogas) energy

Table 1. Summary of the review of literatures for determinants of households' behaviour towards modern energy technology adoption choices

Author/s	Title	Methodology	Findings
Shallo & Sime, 2019	Determinants of functional status of family size bio-digesters: empirical evidence from southern Ethiopia	Orderd logistic regression	Sex, household income, distance to the market place, follow-up and support affect the functional status of the bio-digester.
Wassie et al., 2021	Determinants of household energy choices in rural sub-Saharan Africa: An example from southern Ethiopia	Multivariate probit	Age, education, household size, land size, distance to market, and credit access influence households' energy choice.
Ahmar et al., 2022	Households' Energy Choices in Rural Pakistan	Multivariate probit	Sex, education, livestock holding size, and credit access affects energy choice.
Guta, 2020	Determinants of household use of energy-efficient and renewable energy technologies in rural Ethiopia	Generalized ordered probit	Land size, cattle head, family size, and sex affect adoption of renewable energy technologies.
Karanja and Gasparatos (Karanja & Gasparatos, 2020)	Adoption of improved biomass stoves in Kenya: a transect-based approach in Kiambu and Muranga counties	Probit regression	Education, household size, income, land size, extension visit, and distance to woodland affects adoption of improved cook-stove.
Bahta & Berhe, 2020	Adoption Determinants of Improved Cook Stove Among Rural Households: The Case of Benishngul Gumuz Reginal State, Ethiopia	Logistic regression	Income, distance to market, early adopters' neighbors affect adoption of the improved cook stove.
Shallo et al., 2020	Determinants of biogas technology adoption in southern Ethiopia	Logistic regression	Education, income, distance to wood source, and credit access affects adoption of bio-digester.
Kelebe et al., 2017	Determinants for adoption decision of small scale biogas technology by rural households in Tigray, Ethiopia	Logistic regression	Age, family size, level of education, cattle size owned, distance to firewood collection site, and distance to nearest market affects biogas technology adoption
Yu & Luo, 2022	Farming experience and farmers' adoption of low-carbon management practices: the case of soil testing and fertilizer recommendations in China	Logistic regression	Farming experience affects technology adoption among poor households.
Zeng et al., 2022	The impacts of observational learning and word-of-mouth learning on farmers' use of biogas in rural Hubei, China: does interpersonal trust play a role?	Logistic regression	Observational learning and interpersonal learning determine the adoption of biogas technology.

(*Continued*)

Author/s	Title	Methodology	Findings
Conley & Udry, 2010	Learning about a new technology: Pineapple in Ghana	Logistic regression	Neighbors' practices influence farmers' adoption decisions of technologies.
Krishnan & Patnam, 2014	Neighbors and extension agents in Ethiopia: Who matters more for technology adoption?	Panel data analysis	Agricultural extension visits and adopter neighbors influence agricultural technology adoption.
Wang & Yu, 2017	Social interaction-based consumer decision-making model in social commerce: The role of word of mouth and observational learning	Logistic regression	Word of mouth from neighbors influences product information.
Benjamin, 2013	Effectiveness of Technology Dissemination and Adoption among Farmers in Cross-River State, Nigeria	t-test /descriptive	Adoption of technology is affected by the effectiveness of extension services.
Van der Kroon et al., 2013	The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis	Review	Socio-economic characteristics of households influence the level of technology adoption.

Sources: Literature review (2022)

Table 2. Proportional sample distribution

No.	Name of District	Target Population Households	Sample taken
1	Gozamin	25,201	149
2	Awabel	19,581	116
3	Enebse Sar Midir	23,184	138
Total		67,966	403

Source: *East Gojjam Zone, Agriculture Office (2021)*

sources. However, the joint determinants of rural households' decisions to adopt modern energy technology, primarily the choice of solar, improved cook stove, and biogas technology energy options, have yet to be examined. As a result, using rural households in East Gojjam Zone as a case study, this study seeks to analyze the factors influencing rural household decisions on modern energy choices such as solar, improved cook stoves, and biogas technology adoption.

3. Conceptual framework

Figure 1 depicts the conceptual framework of the study, as well as the important variables involved and how they were connected.

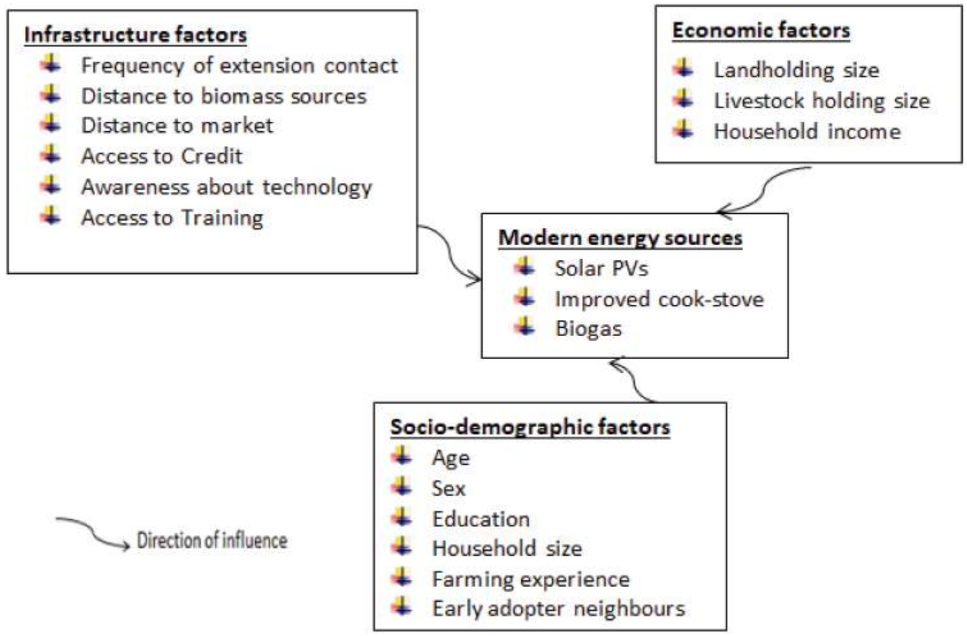
4. Research methodology

4.1. Description of the study area

This study was conducted in three randomly selected rural districts of the East Gjjam Zone of Ethiopia. These were the districts of Gozamin, Awabel, and Enebse Sar Midr (Figure 1).

Figure 1. Conceptual framework of the study.

Source: authors compilation based on literature.



Administratively, the zone is one of 12 in Ethiopia's Amahara National Regional State, with a total of 17 rural districts (Woredas) and 5 municipal cities, and its capital is Debre Markos town. The districts are further subdivided into kebeles, Ethiopia's smallest administrative units. It is bounded on the north by the South Gondar zone, on the east by the South Wollo zone, on the south by the Oromia Regional State, and on the west by the West Gojjam zone. It can be found between 9′50" and 11′15" latitude North and 37′02" and 38′32" longitude East. The East Gojjam zone has a total population of 2,740,625 people, with approximately 84 percent of the population living in rural areas and relying on agriculture for a living (Zone, 2020a). The study's target population was rural household heads in the East Gojjam Zone, which included 377,021 rural household heads, with 326,575 male-headed households and 50,446 female-headed households (Zone, 2020a). Since 2013, renewable energy technology has been introduced and disseminated in rural households in the East Gojjam Zone (Zone, 2020b). However, many rural households are yet to adopt modern energy technologies, leaving them dependent on traditional energy sources.

4.2. Sources and method of data collection

The cross-sectional data type was used to conduct this study, and the data was both quantitative and qualitative in nature. Semi-structured questioners (which included both open-ended and closed-ended questions) and personal interviews were used to collect data. The data collected focused on socioeconomic and demographic characteristics as well as factors influencing household modern energy choice decisions. Enumerators who work as development agents and technical assistants in the district's rural kebeles were chosen. Enumerators were trained in data collection objectives and techniques prior to data collection. The questionnaire was then tested on some rural households to assess its appropriateness, clarity, interpretation, and relevance; to make sure that important issues were raised; and estimate the time required for an interview. To make the interview more user-friendly, the questioners have been translated from English to Amharic (the local language). Following the questionnaire, enumerators conducted face-to-face interviews with sample households to collect quantitative and qualitative information.

4.3. Sampling technique

The study's sample districts and households were chosen using a multistage stratified random sampling approach. To capture the potential effects of agro-climatic related factors on households' energy choice, the 17 districts of East Gojjam Zone were clustered into three agro-climatic zones:

highland, midland, and lowland in the first stage. Following that, one district from the highland group, one from the midland group, and one from the lowland group were chosen at random. The highland district of Gozamin, the midland district of Awabel, and the lowland district of Enebse Sar Midir were chosen for this. In 2020, Gozamin district had 25,201 rural households, Awabel had 19,581 households, and Enebse Sar Midir also had 23,184 rural households.

As a result, the optimal sample size was determined in the second stage using the (Cochran, 1977) sample size formula. The Cochran sample size calculation used 95 percent confidence, 5% precision (for a large sample size with a smaller allowable error between sample estimates and true population values), and p = 0.5 (for an unknown population proportion to generate the largest sample size). Thus, (Cochran, 1977) sample size determination looks as follows:

$$n = \frac{z^2pq}{e^2}$$

So,

$$n = \frac{z^2pq}{e^2} = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = \frac{(3.8416)(0.25)}{0.0025} = \frac{0.9604}{0.0025} = 384.16 \simeq 384$$

Where, **n**= is the desired sample size, **p**= 0.5 is the assumed population proportion expected to have access to renewable energy sources, **q = 1-p**= 0.5 is the assumed population proportion which is not expected to have renewable energy sources, **e**= 0.05 is the marginal error or desired precision at 5%, **Z =** 1.96, critical value of 95% confidence level.

A total of 403 rural households were sampled. As shown in Table 2, about 149 households were collected from the Gozamin district; 116 from the Awabel district; and 138 from the Enebse Sar Midir district. In the third stage, three kebeles were chosen at random from each sample district, and the sample size calculated from each district was distributed to the three kebeles using proportionate sampling. Finally, probability random sampling was used in each household of the selected kebeles that use at least one modern energy source, such as solar PVs or improved biomass.

4.4. Method of data analysis

The study was examined using descriptive statistics and econometric analysis. The descriptive analysis was done using mean, frequency, percentage, and table data, while the econometric model was analyzed using the multivariate probit model (MVP). Multivariate probit model was used to determine factors affecting rural households' energy choice. The multivariate probit model simultaneously shows the influence of a set of explanatory variables on the adoption of modern energy technology while accounting for potential correlations between unobserved disturbances as well as the relationship between the choices of different modern energy sources (Belderbos et al., 2004).

Smallholder rural households in the study area have access to a variety of modern energy sources, including solar, improved cook stoves, and biogas technology. Thus, in this study, rural households demand a variety of energy sources that allow them to select more than one energy source that is not mutually exclusive for lighting, cooking, organic soil fertilizer, and other purposes. Given the possibility of simultaneous energy source selection and the potential correlations between these alternative modern energy choice decisions, a multivariate probit model was appropriate and used to capture household variation in energy selection and estimate several binary outcomes jointly.

The selection of appropriate energy choice *i* by household *j*is Y_{ij}^{A} defined as the choice of household j to adopt modern energy sources i (Y_{ij}^{A} = 1) or not (Y_{ij}^{A} = 0) is expressed as follows (Equation 1):

$$Y_{ij}{}^{A} = \begin{cases} 1\ if\ Y_{ij}{}^{A} = X_{ij}{}^{A}a_{ij} + \mathcal{E}^{A} \geq 0 \Leftrightarrow X_{ij}{}^{A} \geq -\mathcal{E}^{A} \\ 0\ if\ Y_{ij}{}^{A} = X_{ij}{}^{A}a_{ij} + \mathcal{E}^{A} < 0 \Leftrightarrow X_{ij}{}^{A} < -\mathcal{E}^{A}, \end{cases} \tag{1}$$

Where a_{ij} a vector of simulated maximum likelihood (SML) parameters to be estimated; $\mathcal{E}^{A}$ is a vector of correlated error terms under the assumption of normal distribution, $Y_{ij}{}^{A}$ is dependent variable for alternative modern energy choices simultaneously and $X_{ij}{}^{A}$ combined effect of the explanatory variables.

The multivariate probit (MVP) simultaneous model was used because the choice of one type of energy source is dependent on the choice of the other, and smallholder household choice decisions are interdependent and must be estimated concurrently (Melese et al, 2018). Because modern energy choice decisions in rural households were expected to be influenced by the same set of explanatory variables. Therefore, the MVP model is predicted as Equation 2.

$$\begin{cases} Solar_{j} = X_{1}'\beta_{1} + \mathcal{E}^{A} = \\ cook\,stove_{j} = X_{2}'\beta_{2} + \mathcal{E}^{B} \\ Biogas_{j} = X_{3}'\beta_{3} + \mathcal{E}^{C} \end{cases} \tag{2}$$

Where $Solar_j$, Improved cook $stov_j$, and $Biogas_j$ are binary variables taking values 1 when household j selects solar, improved cook stove, and biogas technology adoption choices, respectively, and 0 otherwise; X1 to X3 are vector of variables; β1 to β3 a vector of simulated maximum likelihood (SML) parameters to be estimated and ε disturbance term. In multivariate model, the use of several modern energy choices simultaneously is possible and the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity and ρij represents the correlation between endogenous variables, given by Equation 3;

$$\begin{pmatrix} \varepsilon^{A} \\ \varepsilon^{b} \\ \varepsilon^{C} \end{pmatrix} \ldots N \left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} 1_{p} & 12_{p} & 13 \\ p21 & 1 & p23 \\ p31 & p32 & 1 \end{pmatrix} \right] \mathrm{E}(\mathcal{E}/\mathrm{X}) = 0\mathrm{Var}(\mathcal{E}/\mathrm{X}) = 1Cov(\mathcal{E}/\mathrm{X}) = \rho \tag{3}$$

ε1to ε3 are correlated error terms in a seemingly unrelated multivariate probit model; and ρ's are tetra choric correlations between endogenous variables. Possible explanatory variables and associated hypothesis are presented in Table 3.

5. Results and discussions

5.1. Socio-economic characteristics of sample households

The socioeconomic characteristics of sample households play an important role in promoting or discouraging profitable modern energy choices. After excluding those with missing values, the total final sample for this study consisted of 317 observations, as shown in Table 4. Male-headed households accounted for 89% of all sample survey respondents. The average age of sample household heads was 51.65 years, with a standard deviation of 13.58 years, implying that the majority of the sample households were under the prime-age group. Similarly, the sample households' average education level was 1.51 years of schooling. In terms of family size, the average family size was 4.79 members per household. The size of a family is a proxy for the labor force, which increases the adoption of modern energy technologies. This implies that a large family size in a household has the potential to generate more income and, as a result, modern energy technology.

Table 3. Summary of explanatory variables and working hypothesis		
Variables	**Measurements**	**Expected outcome**
Sex of household head	Dummy (1 for male, 0 otherwise)	+
Age of household head	Continuous (years)	+
Education (in year of schooling)	Continuous (grade)	+
Household Size	Continuous (no of person)	+
Farming experience	Continuous(in years)	+
Landholding size	Continuous (In hectare)	+
Livestock holding (TLU)	Continuous (in TLU)	+
Household Income	Continuous (In Birr).	_
Frequency of extension contact	Continuous (in walking hours)	_
Access to credit	Dummy (1 has got credit, 0 otherwise)	–
Distance to biomass sources	Continuous (in walking minutes)	_
Awareness about technology	Dummy (1 yes, 0 otherwise)	_
Distance to market	Continuous (in walking minutes)	+
Access to training	Dummy (1 has training access, 0 otherwise)	–
Presence of early neighbour adopters	Dummy (1 has early neighbouring adopter, 0 otherwise)	+

In the study area, the average experience of farmers in agricultural production was about 29.46 years, implying that sample households had good experience in farming. A household's average landholding size was 1.83 hectares. Thus, as household landholding size increases, so does the demand for and selection of appropriate modern energy sources. Furthermore, the respondent's average livestock holding was 6.15 Tropical Livestock Units (TLU). This implies that households with a lot of livestock can afford to invest in modern energy technology. Livestock holding is also regarded as a key input for bio-digester adoption in order to increase energy sources from biogas and improve the long-term functionality of bio-digester plants. Similarly, household income is a determinant of rural households' energy choices. The average annual income of respondent households was 76,857.14 Birr.

Another important factor in modern energy choices is extension service. Increasing access to extension services improves the return and functionality of adopting modern energy technology. Their time of contact during technology installation will increase energy sources from the technology and its returns, as will their time spent training farmers on how to use the technology. Table 4 shows that the average frequency of extension contact for sample households was approximately 2.63 times per year. According to the survey results, the average distance required for households to walk to biomass sources was 11.35 minutes. This means that households located closer to biomass fuel sources may overlook the adoption of modern energy technology and the selection of appropriate energy options. Besides, the average distance to modern energy technology providers, was 11.39 walking minutes. As the distance increases, it's difficult to have access to finding technology spare parts and maintenance service from technology experts.

Furthermore, credit is available to 24% of the sample households. Farmers who have access to credit can reduce their financial constraints and try to choose the most appropriate modern energy sources. Furthermore, 90% of the sample households were aware of modern energy sources and technology providers in their area. 49% of average households also receive energy technology utilization training from technical experts. Finally, 69.4% of the households have neighbors who use early-modern energy technology. This means that a large number of farmers base their energy choices on the experiences of their neighbors.

Table 4. Characteristics of energy adopter households (continuous and dummy variables)

Continuous Variable	Mean	Standard deviation
Age of household head	51.65	13.58
Education level of household head	1.51	2.79
Household Size	4.79	1.62
Farming experience	29.46	12.97
Landholding size	1.83	1.25
Livestock holding (TLU)	6.15	3.03
Household Income	76,857.14	39,799.03
Frequency of extension contact	2.63	3.16
Distance to biomass sources	11.35	7.95
Distance to market	11.39	8.98
Dummy Variables	**Frequency**	**Percentage**
Sex (male)	281	88.64
Access to Credit (yes)	76	23.97
Awareness about technology (yes)	284	89.59
Access to Training	155	48.90
Presence of early Neighbour adopters	220	69.40
Total observation 359		

Source: Authors computation from sample survey data (2022)

Rural households in the study area adopt three alternative modern energy sources to maximize their energy demand from their energy choice. These alternative modern energy sources were solar, improved cook stoves, and biogas technologies, which are mostly chosen in combination with one another.

As shown in Table 5, one of the most relatively adopted energy technology by rural household is improved cook stove which was chosen by about 66.56% of respondents, while solar and biogas technologies was adopted by 63.72% and 31.86% of households, respectively.

In Table 6 below, the consumption choice of modern energy technology adoption was explored where respondents were asked to answered the purpose of adoption energy technologies.

The result indicates that adoption of solar, improved cook stove, and biogas technologies is used for generating lighting, cooking, and other sources. Approximately 82% of respondents chose alternative energy technology for lighting. Furthermore, 73.5% of respondents use the given energy sources for cooking. In contrast, 13.88% of the sample households use the three types of energy sources for purposes other than lighting and cooking. This suggests that the adoption of solar, biogas, and improved cook stove technology serves additional purposes for rural households. According to the qualitative data, these energy sources are also used for charging mobile batteries with solar and producing bio-slurry fertilizer with biogas technology adoption. Previous research (Ahmar et al., 2022; Chekol et al., 2022; Wassie et al., 2021) supports the findings.

5.2. Determinants of alternative modern energy technology adoption choices: Estimation of multivariate probit (MVP) Model

Rural households in East Gojjam Zone adopt three alternative modern energy choices to meet their energy demand, such as solar energy, improved cook stoves, and biogas technology. These three energy choices were considered in the econometric model. The result of the multivariate probit regression model (MVP) is presented in Table 7.

Table 5. Proportion of energy choices

Decision	Alternative modern energy choices		
	Solar	**Cooking stove**	**Biogas**
Number of respondents (yes)	202	211	101
Proportion (%)	63.72	66.56	31.86

Source: Authors computation from the sample survey data (2022)

Table 6. Purpose of modern energy technology adoption choices

Decision	Purpose of adoption of modern energy sources		
	Lightening	**Cooking**	**Others**
Number of respondents (yes)	261	233	44
Proportion (%)	82.33	73.50	13.88

Source: Authors computation using survey data (2022)

The Wald test (chi2 (45) = 243.39, Prob > chi2 = 0.0000) is strongly significant at 1% significant level, which indicates that the subset of coefficients of the model is jointly significant and the explanatory power of the factors included in the model is satisfactory; thus, the MPV model fits the data reasonably well. At a 1% significance level, the simulated maximum likelihood test (LR chi2 (3) = 52.0461, Prob > chi2 = 0.0000) of the null hypothesis of independence between the modern energy choice decision (r21 = r31 = r32 = 0) is significant. Therefore, the null hypothesis that all the r (rho) values are jointly equal to 0 is rejected, indicating the goodness of fit of the model and supporting the use of the MVP model over the individual probit model. This verifies that separate estimation of energy choice is biased and the decisions to choose the three modern energy sources are interdependent among household decisions.

Individual rho (ρij) values indicate the degree of correlation between each pair of the dependent variables. The result of the model showed that the correlation between the choice of an improved cook stove and solar (ρ21) and the correlation between the choice of biogas and solar (ρ31) was negative and statistically significant (Table 7). This finding indicates that households who adopt improved cook stoves are less likely to adopt solar (ρ21). Equally, households that adopt biogas technology are less likely to adopt solar. This could imply a substitution effect between improved cook stoves and solar, as well as biogas and solar energy sources.

The simulated maximum likelihood estimation also displays the chance that each energy source will succeed marginally. In comparison to the likelihood of choosing solar (64.18%) and biogas (31.1%) technology, the likelihood of choosing an enhanced cook stove (65.8 percent) is relatively high. Choices indicate that those families are less likely to jointly select the three energy sources concurrently when it comes to the probability of success and failure of modern energy sources. When compared to the possibility that they wouldn't jointly choose them, rural families had a very high likelihood of choosing the three energy sources, with a joint probability of success of 7.48% (while the joint probability of failure is 3.19%). This suggests that there is a strong likelihood of picking the shared energy sources. According to this finding, the best combination of contemporary energy sources would depend on several aspects that are specific to each energy source.

As a result, Table 7 displays the estimated coefficients (βi) and Table 8 displays the marginal probability effect (Yi = 1) of the various factors influencing the adoption of alternative

Table 7. Multivariate probit coefficient estimates of factors influencing alternative modern energy choices

Variables	Alternative modern energy choices		
	Solar	Cook stove	Biogas
	Coeff (Se)	Coeff (Se)	Coeff (Se)
Sex	−0.170 (0.28)	0.431 (0.29)	0.196 (0.33)
Age of household head	−0.0002 (0.01)	0.019 (0.01)	0.024 (0.01)
Education level of household head	0.128 (.03) *	−0.107 (0.03) *	−0.008 (0.03)
Household Size	0.018 (0.05)	−0.170 (0.06) *	0.033 (0.06)
Farming experience	0.012 (0.01)	−0.032(0.01)***	−0.021 (0.01)
Landholding size	0.194 (0.09) **	−0.150 (0.10)	0.077 (0.10)
Livestock holding (TLU)	−0.006 (0.03)	0.161 (0.03) *	0.028 (0.03)
Household Income (log)	−0.382 (0.17) **	0.573 (0.19) *	−0.209 (0.19)
Frequency of extension contact	−0.070 (0.03) **	0.072(0.03) ***	0.176 (0.03) *
Access to credit	0.484 (0.22) **	−0.164 (0.24)	−0.916(0.35) *
Distance to biomass sources	−0.023(0.01)***	0.033 (0.01) **	0.048 (0.01) *
Awareness about technology	0.650(0.33) ***	1.25 (0.40) *	−2.163(0.43)*

(Continued)

Table7. (*Continued*)

Variables	Alternative modern energy choices		
	Solar	**Cook stove**	**Biogas**
	Coeff (Se)	**Coeff (Se)**	**Coeff (Se)**
Distance to market	0.041 (0.01) *	−0.019 (0.01)	−0.162(0.02) *
Access to Training	−0.463 (0.21) **	1.295 (0.22) *	0.706 (0.26) *
Presence of early Neighbour adopter	1.237 (0.24) *	0.634 (0.24) **	_0.57(0.29)***
Constant	2.540 (1.88)	−8.436 (2.12)	3.011 (2.15)
Multivariate probit (SML, # draws = 5) Log likelihood = —−350.55533		Number of obs = 317 Wald chi2(45) = 243.39 Prob > chi2 = 0.0000	
Predicted probability	0.6418873	0.6586405	0.3112481
Joint probability (success)	0.0747766		
Joint probability (failure)	0.0319531		
Estimated correlation matrix	ρ1(Y1	ρ2(Y2)	ρ3(Y3)
ρ1(Y1)	1.00		
ρ2(Y2)	−0.53 * (0.10)	1.00	
ρ3(Y3)	−0.50 * (0.09)	−0.03 (0.16)	1.00

Likelihood ratio test of rho21 = rho31 = rho32 = 0:
chi2(3) = 52.0461
Prob > chi2 = 0.0000

*, **, and *** *are significant at 1%, 5%, and 10% level of significance, respectively. Y1, Y2, and Y3, are Solar, Cooking stove, and Biogas, respectively.*

Source: *Own survey results (2022)*

Table 8. Marginal effects of factors influencing alternative modern energy choices

	Alternative modern energy choices		
	Solar	Cookstove	Biogas
Variables	Margin (Se)	Margin (Se)	Margin (Se)
Sex	−0.109 (0.04)	0.276 (0.11)	0.125 (0.05)
Age of household head	−0.0001(0.00)	0.012 (0.005)	0.015 (0.006)
Education level of household head	0.082 (0.03) *	−0.068 (0.02) *	−0.005 (0.002)
Household Size	0.011 (0.004)	−0.109 (0.04) *	0.021 (0.009)
Farming experience	0.008 (0.003)	−0.02(0.008)***	−0.013 (0.005)
Landholding size	0.125 (0.05) **	−0.096 (0.04)	0.049 (0.02)
Livestock holding (TLU)	−0.003 (0.001)	0.103 (0.04) *	0.018 (0.007)
Household Income (log)	−0.245 (0.10) **	0.368 (0.15) *	−0.134 (0.05)
Frequency of extension contact	−0.045 (0.01) **	0.046(0.01) ***	0.113 (0.04) *
Access to credit	0.310 (0.13) **	−0.105 (0.04)	−0.588 (0.24)*
Distance to biomass sources	−0.01(0.006)***	0.021 (0.009)**	0.031 (0.01) *
Awareness about technology	0.417 (0.17)***	0.804 (0.33)*	−1.38 (0.58) *
Distance to market	0.026 (0.01) *	−0.012 (0.005)	−0.104 (0.04) *
Access to Training	−0.297 (0.12) **	0.831 (0.34) *	0.453 (0.19) *
Presence of early Neighbour adopter	0.794 (0.33) *	0.407 (0.17) **	−0.370 (0.15)***

, **, and * are significant at 1%, 5%, and 10% level of significance, respectively.*

Source: *Own survey results (2022)*

contemporary energy technology options. Ten of the 15 explanatory factors in the MVP model had a significant impact on solar energy, ten had a significant impact on improved cook stoves; and seven had a significant impact on biogas energy choice at the 1%, 5%, and 10% significance levels. As a result, the model's findings can be trusted.

The education level of the household head has a positive correlation with the selection of solar and a negative correlation with the selection of a better cook stove. The marginal effect shows that an addition of one more year of schooling to a household head increases the chance of adopting solar by 8.2% while decreasing the chance of adopting an improved cook stove (ICS) by 6.8%. With additional years of education comes an increase in the demand for renewable energy sources as well as investments in good health. This is due to the fact that an educated family head will be more aware of the benefits of employing clean energy sources (Ahmar et al., 2022; Wassie et al., 2021). While household size has a negative and significant influence on the choice of an improved cook stove. The estimated marginal effect, the addition of one more member to a household, decreases the chance of adopting ICS by 10.90%. There could be two causes for this. First, a household with several children needs to spend a lot of money on their upkeep in addition to using current energy sources (Karanja & Gasparatos, 2020). Due to this, it could be challenging to set up numerous sustainable energy sources for a larger family. Second, the number of households is related to the number of workers available to harvest wood for fuel. It can be assumed that children and women are frequently used as sources of fuel wood and agricultural waste collection in rural areas. For the vast majority of rural households with relatively larger household sizes, wood fuel is the fuel of choice. Because they can efficiently gather enough energy fuel, households with large family sizes tend to use less advanced biomass cook stoves (Van der Kroon et al., 2013).

Those with fewer members frequently use an improved biomass cook stove as a stand-in for fuel-saving technology that uses wood.

Moreover, the decision of a household to use an improved cook stove is significantly and negatively influenced by the experience of the household head in farming. The likelihood of improved cook stove adoption fell by 2% as the family head's years of farming experience increased. This is because farming experience varies considerably and negatively influences small-holder farmers' adoption of low-carbon techniques since they have fewer resource endowments (Yu & Luo, 2022). On the other hand, landholding size has a positive and significant impact on the selection of solar energy. The result shows that one additional hectare of land increases the probability of adoption of solar energy by 12.5%. This result demonstrates the significance of household landholding size on modern energy choices by positively influencing household income to cover the cost of technology adoption (Guta, 2020; Kelebe et al., 2017; Wassie et al., 2021). The estimated livestock holding coefficients in tropical livestock units (TLU) also have a positive and significant effect on rural households' decisions to choose an improved cook stove. Households with one additional livestock holding increase their likelihood of selecting an improved cook stove by 10.3%. This could be because households with a large livestock head increase household income to afford the technology (Guta, 2020; Wassie et al., 2021). Besides, the coefficients and probability estimation effects of household income level are positively and significantly associated with improved cook stove technology but negatively associated with solar energy technology. One dollar increase in the income of a household increases the likelihood of using ICS by 36.8% and decreases the likelihood of adoption of solar by 24.50%. This suggests that wealthier households are more likely to choose an improved cook stove because it reduces the demand for firewood and needs to improve family health. At the same time, higher-income households are less likely to install solar PV systems because they can easily switch to other sources of energy, such as electricity and biogas, for demanding multipurpose activities. The result is supported by the previous findings (Bahta & Berhe, 2020; Best & Chareunsy, 2022; Karanja & Gasparatos, 2020).

Extension agents have been identified as an important determinant of technology diffusion in rural households. The findings of the study indicated that the frequency of extension contact has a positive and significant influence on cook stoves and biogas but a negative and significant influence on solar selection. Getting service from extension agents, in particular, increases the likelihood of adopting biogas and improved cook stoves by 11.3% and 4.6%, respectively, while decreasing the likelihood of adopting solar energy by 4.5%. This implies that having frequent contact with agricultural extension agents increases the likelihood of receiving relevant information, as well as training and educating farmers about the benefits and drawbacks of the technology, and thus increases adoption choice. Implying that learning from extension agents accelerates the transfer of information and improves farmers' adoption of modern energy technology (Karanja & Gasparatos, 2020; Krishnan & Patnam, 2014). However, due to a poor extension service delivery system and a lack of logistics associated with a poor extension program and message design, the adoption of some energy sources is poor. Therefore, the rate of technology adoption is determined by the quality of the service delivery method rather than the frequency of contact alone (Benjamin, 2013). Credit availability is also associated with positive and significant choices for solar technology adoption, as well as negative and significant choices for biogas technology adoption. Households with access to credit are 31% more likely to use solar energy and 58% less likely to use biogas. Providing innovative and sustainable credit access to households makes technology affordable to all consumers, including the very poor, while ensuring the sector's long-term viability (Ahmar et al., 2022). In contrast, the presence of non-innovative financing mechanisms due to credit market imperfections (higher interest rates or higher prices) reduces the likelihood of technology adoption compared to their counterparts. The impact of credit on energy adoption, on the other hand, is determined by a cost-benefit analysis of adoption. If the biogas is not functional after adoption, rural households will be unwilling to risk the high cost of adoption for bio-digesters in comparison to solar, which requires a low cost of adoption. This is due to smallholder farmers' aversion to risk (Wang et al., 2011).

The coefficients and marginal effects of walking distance to biomass sources are significantly positive for improved cook stoves and biogas, but negative for solar use. With each additional minute of walking from homesteads to the woodland, the probability of adopting an improved biomass cook stove and biogas increases by 2.1% and 3.1%, respectively, while decreasing the use of solar energy by 2.6%. This indicated that households living in close proximity to biomass fuel sources are more likely to adopt improved cook stove and biogas technology, as these technologies are used as a substitute for wood fuels. On the other hand, households with close proximity to their firewood sources are more likely to use solar energy because it is less expensive than other options (Karanja & Gasparatos, 2020; Shallo et al., 2020; Kelebe et al., 2017). The estimated marginal effect of rural household heads who have knowledge and awareness about modern energy technology is that they are also more likely to adopt solar and improved cook stoves by a factor of 41.7% and 80.4%, respectively, and less likely to adopt biogas by a factor of 113.8%, when compared to those households who do not know about the benefits and technology providers in their local area. Households that are well informed about the advantages of modern energy technology over other sources of power develop a positive attitude toward health, efficiency, and environmental sustainability (Benjamin, 2013). However, a major impediment to the spread of energy technology in developing countries is a lack of awareness and relevant information (Shallo & Sime, 2019; Van der Kroon et al., 2013). Distance to a market with modern energy technologies is also positively related to solar technology adoption and negatively related to biogas technology adoption. The marginal effect indicates that for every 2.6% increase in the distance between a household's homestead and the availability of technology, the likelihood of adopting solar and biogas increases by 2.6% and decreases by 10.4%, respectively. This means that households living a long distance from technology providers and markets will have to pay more for transportation, and it may be difficult to transport biodigester spare parts and receive maintenance service deliveries. However, transporting solar energy may not be difficult because its physical weight is easy to hold over long distances. Lack of biogas key spare parts near farm households appears to have a negative impact on biodigester adoption and functionality (Shallo & Sime, 2019; Wassie et al., 2021). As a result, even wealthy households living in rural areas with long distances may be forced to continue using biomass energy sources. The findings are consistent with previous research (Bahta & Berhe, 2020; Kelebe et al., 2017).

Similarly, access to training is significantly and positively associated with the choice of an improved cook stove and biogas, but significantly and negatively associated with the choice of solar use. The marginal effect shows that households with access to technical training are more likely to adopt improved cook stoves and biogas by a factor of 83.1% and 45.3%, respectively, while households with no training access are less likely to adopt solar by a factor of 29.7%. Farmers learn through observational training from technical instructors, which makes demonstration activities much more effective and increases the likelihood of technology adoption (Zeng et al., 2022). The provision of technical training about utilization and its effects increased the likelihood of trainee technical skill improvement and increased the choice of improved cook stoves and biogas (Benjamin, 2013). Moreover, the relationship between early neighbors and the choice of solar and cook stove technology was positive, but it was negative with the choice of biogas technology. Farmers make their technology selection after observing actual practice and gathering word-of-mouth information from their neighbors (Krishnan & Patnam, 2014; Zeng et al., 2022). Farmers can learn from their neighbors by observing those who face similar shocks or returns when making decisions (Conley & Udry, 2010). Furthermore, word-of-mouth information from neighborhoods definitely influenced the choice and adoption of technology due to spill-over effects, as many people understood the new technology's success and failure stories (Bahta & Berhe, 2020; Wang & Yu, 2017). When word-of-mouth explicitly details a subject's positive experience, the likelihood of adopting the technology increases; when word-of-mouth explicitly details a subject's negative experience, the likelihood of choosing the technology decreases. In this study, where the first biogas installations performed poorly, unsatisfied users' word of mouth discouraged other potential users from building their own installations (Parawira, 2009).

6. Conclusion and recommendations

Energy has become known as a "strategic commodity," and any uncertainty about its supply might undermine the economy's functioning. Many rural communities in developing countries continue to rely on biomass for energy, which has a negative impact on their socioeconomic development. Following the United Nation's Sustainable Development Goals—zero hunger and affordable modern/clean energy for all—many developing nations are now taking substantial initiatives to enhance rural clean energy access. Unfortunately, in poor rural Ethiopia, households either rely on traditional energy sources or do not use modern cooking and lighting as the potential level. Thus, this study considers the various energy sources that are available to rural households for cooking and lightening purposes and investigate the role of socio-demographic, economics, and infrastructure related variables on households' decision of modern energy choices in East Gojjam Zone of Ethiopia. This study employed multivariate probit (MVP) estimation technique to analyse the data collected from 317 rural survey households.

The study's key findings of this study indicate that improved biomass cook stoves are the primary source of energy for rural households in the study area, followed by solar PVs and biogas technology adoption. These interdependent technological adoptions were important sources of energy for rural households in the study area. Households choose multiple modern energy sources based on their demand for and the cost of adoption. Households that choose improved biomass cook stoves are less likely to adopt solar power, while households that choose biogas are less likely to adopt solar energy sources.

While examining the determinant variables, the MVP result shows that education level, land size, credit availability, awareness, distance to market, and early neighbour adopters have positive effects on the choice of solar energy sources, whereas livestock holding, household income, extension contact, distance to biomass sources, and training access have negative effects. Besides this, the estimated MVP for improved cook stoves is positively influenced by livestock holding, income, extension contact, distance to biomass sources, awareness, training access, and early adopters, while education level, household size, agricultural experience, land size, access to credit, and distance to market all have a negative influence. Moreover, extension contact, distance to biomass sources, and availability of training have a positive impact on the choice of biogas energy sources, whereas credit access, awareness, distance to market, and early adopters have a negative effect. When comparing the propensity to use modern energy sources in the study area, infrastructural development were identified as critical. As a result, the government should expand infrastructure service provision to every rural household community. Furthermore, it is also recommended that agricultural and rural development agents and non-governmental development agents work together at the kebele level to improve access to energy infrastructure and eliminate energy poverty from the rural communities of East Gojjam Zone.

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