FOLUR Project "Preventing Forest Loss, Promoting Restoration, and Integrating Sustainability into Ethiopia's Coffee Value Chains and Food Systems"

Study Report on Alternative Sources of Household Energy (Type, Local Production Potentials, Affordability, and Challenges) and Projected Demands for Fuel-Saving Technologies in FOLUR Ethiopia Project Areas

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Table of Contents Page

List of Tables

List of Figures

Executive summary

This study was conducted across 4 regional states, 13 selected FOLUR project districts and 26 kebeles to identify and categorize existing and potential alternative household energy sources, assess their local production potential, evaluate affordability and accessibility for households, and investigate key socio-economic, institutional, and technical challenges affecting adoption and expansion. The overall objective of the study is to assess the current and projected demand for fuel-saving technologies, examine community awareness, perceptions, and willingness to adopt alternative energy solutions, and evaluate the potential contribution of alternative energy technologies to reducing the rate of deforestation. The data was collected from 2637 households through structured household survey, 78 key informants (KIIs) and 26 focus group discussions (FGDs) and literature review on the contribution of alternative renewable energy technologies for reducing deforestation rate via fuelwood saving. The collected data was analyzed using descriptive statistics, advanced econometrics models and narrations of qualitative data.

Types of alternative household energy sources

The study conducted across 13 FOLUR project districts revealed that household energy consumption is heavily dependent on traditional biomass sources. Dry wood remains the dominant fuel, used by 94.54% of households for cooking and 64.53% for baking. Charcoal, crop residues, and animal dung also serve as important supplementary fuels. Other energy alternatives such as electricity are rarely used, and 81.09% lack access to grid electricity. Among alternative energy options, improved cookstoves (ICS) are used by 10.99% of households, primarily the Mirt stove model. Biogas adoption stands at 0.76%, while solar energy mainly used for lighting rather than cooking is adopted by 39.75% of households. These findings demonstrate a strong dependence on traditional fuels and a slow transition toward alternative and fuel-efficient energies in the forest areas of FOLUR.

Fuel choice factors

Household energy choices in the FOLUR project areas are influenced by a range of socio-economic, demographic, and resource-related factors. Firewood use is more common among male-headed, less-educated households located close to forests, where wood is easily available. Charcoal tends to be used by older, educated, and married households with larger family sizes and separate kitchens often as a substitute for firewood in areas distant from forests. Animal dung is typically used by educated, married households with livestock ownership; its use increases with distance from forests but decreases among beekeepers. The choice of dung by educated households may reflect a combination of practical and economic considerations: dung is freely available on farms with livestock, can serve as a reliable fuel when firewood is scarce, and is easier to store and handle compared to another biomass. Crop residues are mainly used in households located farther from forests and those with separate kitchens, but are less likely to be used by female-headed, older, or highly educated households. These patterns indicate that fuel choice is influenced not only by proximity to natural resources but also by education, gender, household composition, livestock ownership, and income-generating activities, highlighting the complex decision-making behind household energy use.

Alternative energy technology factors

Adoption of alternative energy technologies such as ICS, biogas, and solar systems is strongly influenced by household characteristics. The ICS are more likely to be adopted by male-headed, older, and educated households, as well as those engaged in beekeeping. Beekeeping households often generate additional income from honey sales, which increases their financial capacity to invest in improved energy technologies, while their dependence on healthy forest ecosystems can also motivate environmentally conscious energy choices. The ICS adoption is also higher among households using charcoal, but decreases in households with more female members, larger landholdings, or reliance on kerosene. Biogas adoption is positively influenced by education level, charcoal use, and the presence of a separate kitchen, but negatively affected by the presence of kerosene use, and larger landholdings. Households often practice “fuel stacking,” combining multiple fuels and technologies such as firewood with crop residues or improved cookstoves with biogas or solar systems to balance energy needs, reduce costs, and maximize both convenience and energy security. This approach reflects the adaptive strategies households use to cope with limited access, affordability constraints, and variability in fuel availability.

Results from Literature review showed that adoption of improved cookstoves, biogas systems, and solar cooking technologies has shown significant environmental benefits. Improved cookstoves reduce household fuelwood use by 18–54%, lowering CO_2 emissions by 0.3–0.7 tons per household annually. Biogas systems provide even greater savings, cutting 1.1–1.9 tons of fuelwood per household per year and reducing 1.6–2.75 tons of CO_2 emissions per plant. Solar cooking, though less widely adopted, has the potential to save approximately 1.5 tons of fuelwood per stove annually. Beyond energy savings, these technologies contribute to forest conservation by reducing biomass extraction and deforestation pressures, supporting sustainable household energy use and environmental preservation across the country.

Local production potentials

The study highlights varying local production potentials across different energy sources and technologies. Improved cookstoves show the greatest potential for local production and scaling, as they can be built using locally available materials such as clay, metal sheets, and bricks, and require minimal technical expertise. Their compatibility with traditional cooking practices further supports local adoption and production. Biogas has moderate potential in areas with sufficient livestock waste for feedstock, but its development is limited by high upfront costs, lack of materials, and the need for technical training. Solar energy shows high potential due to Ethiopia’s abundant solar radiation, but local production is primarily focused on the assembly and distribution of imported systems. In contrast, firewood and charcoal, though locally abundant, pose sustainability challenges when harvested unsustainably. However, there is significant potential for sustainable production if households and communities adopt practices supported by training, technical guidance, and forest management frameworks.

The recently enacted Forest Management and Conservation Proclamation No. 544/2024 provide a legal basis for sustainable harvesting, encouraging community-based forest management, woodlot development, and regulated rotational harvesting to ensure continuous biomass supply. Improved charcoal kilns, agroforestry woodlots, and on-farm tree planting can enhance production efficiency while minimizing environmental degradation. By aligning local production practices with the provisions of the 544/2024 regulation, traditional energy sources like firewood and charcoal can become sustainable options, contributing to household energy needs without compromising forest health.

Affordability and accessibility

Affordability and accessibility are key determinants of household energy transitions in the FOLUR project areas. Traditional biomass fuels continue to dominate because they are easily accessible and have low short-term costs. While current practices may lead to environmental degradation and high labor demands, they can be sustainable if forests and woodlands are managed properly and collection is regulated. Improved cookstoves are relatively affordable and align with household cooking habits but remain financially out of reach for many rural families without external support or financing.

Biogas technology, though efficient, is constrained by high installation costs and maintenance requirements. Solar systems are increasingly available, particularly for lighting, but solar cooking devices remain expensive and less practical for rural households. Limited access to grid electricity leaves the majority of households without modern energy services. These affordability and accessibility challenges underscore the need for targeted subsidies, financing options, community-based forest management, and infrastructure investments to promote sustainable clean energy adoption.

Challenges affecting adoption

Multiple barriers hinder the widespread adoption of alternative household energy technologies. Economically, the high initial cost of clean energy systems and the lack of financial mechanisms such as microcredit prevent uptake among low-income households. Technically, challenges such as poor product durability, lack of spare parts, and inadequate after-sales services reduce user confidence. Awareness and knowledge gaps are widespread, many households are unfamiliar with the operation, benefits, and maintenance of clean energy systems.

Institutional and policy limitations, including weak local supply chains and minimal government incentives, further constrain market growth. Socio-cultural resistance, especially attachment to traditional cooking methods, remains a significant challenge. Female-headed and less-educated households face greater barriers to adoption, underscoring the need for gender-sensitive and education-focused interventions.

Projected demand for fuel-saving technologies

The study projects that traditional energy sources such as wood, charcoal, and kerosene will continue to dominate in the near future but are expected to gradually decline as cleaner alternative technologies become more accessible. Factors contributing to better accessibility include affordable financing schemes, wider availability of technologies in local markets, targeted community training, government incentives, establishment of cooperatives, private sector engagement, and improved supply chains that reduce distribution constraints. Together, these factors can enhance adoption rates and support a transition toward sustainable household energy use. Fuel-saving technologies particularly ICS, Biogas, Solar, and Grid Electricity are expected to grow by approximately 20% annually over the next decade.

By 2040, over 1,300,000 households in the FOLUR project regions are expected to adopt these technologies, with improved cook stoves leading the transition due to their affordability, cultural compatibility, and ease of use. The projection is supported by the fact that 99% of respondents expressed willingness to adopt alternative energy technologies if training, affordable financing, and technical support were provided. This high level of interest, along with observed early adoption of improved stoves and solar systems and reported benefits such as reduced fuelwood collection and lower costs, signals strong community readiness and substantial potential for scaling sustainable energy solutions.

Policy and intervention implications

To accelerate the shift toward cleaner household energy, the FOLUR initiative should focus on integrated and inclusive strategies. Policies should promote local production of improved cookstoves and solar systems, expand access to microfinance and subsidies, and encourage private-sector participation in energy distribution. Capacity-building programs are essential to improve technical knowledge, maintenance skills, and awareness of the health and environmental benefits of clean energy.

Expanding rural energy infrastructure, fostering innovation, and developing gender-responsive approaches will further enhance adoption rates. The study underscores the importance of sustained policy support, targeted financing, and community engagement to reduce dependence on traditional biomass fuels, promote environmental sustainability, and improve household well-being in FOLUR project areas in particular and forest dependent communities in general.

1. Introduction

1.1. Background and context

Access to clean and affordable household energy is a cornerstone of sustainable development, influencing health, education, gender equality, and environmental sustainability. Despite progress in global energy access, clean cooking technologies have lagged, leaving universal access by 2030 out of reach. In 2022, about 74% of the global population had access to clean cooking fuels and technologies, up from 64% in 2015 (IEA, 2024). Yet, over 2.1 billion people still rely on polluting fuels such as coal, kerosene, and traditional biomass including wood, charcoal, crop residues, and animal dung for cooking, primarily in low- and lower-middle-income countries. Use of these fuels in inefficient stoves or open fires contributes to household air pollution, causing over 3.2 million premature deaths annually, particularly among women and children (WHO, 2022).

Sub-Saharan Africa (SSA) bears the highest burden, with 970 million people (85% of the population) relying on traditional biomass in 2021 (IEA, 2023; Hailu & Kumsa, 2021). Rapid population growth, limited energy infrastructure, and economic constraints reinforce dependence on freely collected firewood, driving deforestation, soil degradation, and gendered labor burdens on women and children. Barriers to cleaner cooking adoption include high costs, limited local technology availability, cultural preferences, weak supply chains, and inadequate financing (Mperejekumana et al., 2024; Acheampong, 2023; Guta, 2018).

In Ethiopia, traditional biomass dominates household energy. Biomass and waste accounted for 86% of final energy consumption in 2022, with electricity contributing only 3% and 44% of households having basic access (IEA, 2024; Padam et al., 2018; Yalew, 2022). Over 90% of household energy for cooking and heating comes from solid biomass—wood, charcoal, crop residues, and dung (Liyew et al., 2024; Benti et al., 2021). Traditional stoves have low conversion efficiency (~12%), leading to inefficient fuel use (Mengistu et al., 2015).

This high dependency on biomass causes environmental and socio-economic impacts: deforestation, land degradation, biodiversity loss, reduced carbon sequestration, indoor air pollution, and health risks (Yalew, 2022; Tucho & Nonhebel, 2015). Biomass energy supply is largely unsustainable, with about one-third of annual woodfuel sourced from forests and woodlands, resulting in approximately 140,000 hectares of forest degradation per year (Dresen et al., 2014; MEFCC, 2017). Firewood collection, mostly undertaken by women and children, also limits education and economic opportunities, perpetuating poverty cycles. Combustion of biomass contributes significantly to greenhouse gas emissions, estimated at 165–219 Mt CO_2e in 2015/16, while fuelwood consumption affected about 730,000 hectares of forests, woodlands, and shrublands (Yalew, 2022; IPCC, 2023).

Transitioning to clean cooking fuels and technologies is therefore crucial to reduce forest pressure, health risks, and environmental degradation. Ethiopia has recognized this need through national strategies such as the Growth and Transformation Plan II (GTP II) and the Climate-Resilient Green Economy (CRGE) initiative, which aim to expand clean energy access and reduce greenhouse gas emissions. Interventions include hydropower, wind, geothermal, and solar energy expansion, alongside household-level technologies such as improved cookstoves (ICS) and biogas digesters (MoWIE, 2019). The CRGE strategy targets the dissemination of 31 million fuelwood-efficient stoves by 2030, with ICS reducing fuelwood use by 35–50% (Mehetre et al., 2017) and a single Mirt stove avoiding ~634 kg of fuelwood per year and sequestering 0.65 tons of CO_2 (Mekonnen et al., 2022).

Despite these initiatives, adoption of clean cooking remains low. Only 7.5% of Ethiopian households had access to clean cooking in 2021, increasing slightly to 8.5% in 2022 (IEA, 2024). Low adoption persists due to limited income, financing options, awareness, technology availability, private sector engagement, and infrastructure constraints (Kebede et al., 2022; Guta, 2020, 2018; Wassie et al., 2021; Mengistu et al., 2016).

Projects like FOLUR Ethiopia aim to integrate household energy solutions into broader landscape restoration, sustainable land management, and rural development strategies. Understanding local production potentials, affordability, and adoption barriers is therefore essential. While prior studies have addressed biomass dependence and adoption challenges (Benti et al., 2021; Tiruye et al., 2021; Kebede et al., 2022), gaps remain in district-specific production potential, affordability thresholds, projected demand for fuel-saving technologies, and gender-inclusive adoption barriers (Guta, 2020; Mekonnen et al., 2022; Wassie et al., 2021).

This study focuses on alternative household energy sources, their production potential, affordability, adoption challenges, and projected demand in 13 FOLUR project districts in Ethiopia. Using both quantitative and qualitative methods, it explores the interaction between energy use, livelihoods, and environmental health, aiming to inform policy interventions that promote sustainable energy, forest conservation, and agricultural productivity.

1.2. Objectives

1.2.1. General Objective

The general objective of the present study was to undertake a comprehensive assessment of alternative sources of household energy and projected demands for fuel-saving technologies in the selected 13 districts of FOLUR Ethiopia project regions.

1.2.2. Specific Objectives

The study is aimed at addressing the following specific objectives: -

- To identify the existing and potential alternative household energy sources in the 13 selected FOLUR project districts.
- To assess the local production potential of alternative energy sources in the study areas.
- To evaluate the affordability and accessibility of alternative household energy sources for households in the study areas.
- To investigate the key socio-economic, institutional, and technical challenges hindering the adoption of alternative household energy sources.
- To estimate the current and projected demand for fuel-saving technologies in the study areas.
- To explore community awareness, perceptions, and willingness to adopt alternative energy and fuel-saving technologies.
- Provide evidence-based recommendations for policymakers, development agencies, and private investors to promote sustainable energy solutions in the study areas.

1.3. Scope of the Study

This study focused on four FOLUR Ethiopia project regions: Oromia, South West Ethiopia, Sidama, and Southern Ethiopia. The study covers 13 woredas and 26 kebeles selected from the four FOLUR regions (Oromia, South West Ethiopia, Sidama, and Southern Ethiopia). Both technical aspects (such as local production potential and availability) and socio-economic factors (such as affordability, gender implications, and cultural acceptance) were considered.

1.4. Significance of the study

The findings from this study offer valuable insights for policymakers, contributing to national and global efforts to achieve the Sustainable Development Goals (SDG7) and mitigate climate change. Specifically, understanding the projected demand for fuel-saving technologies in specific districts, such as 13 districts targeted under the FOLUR Ethiopia project in this study, has potential to provide valuable evidence to support sustainable and inclusive energy policies at both local and national levels. Broadly, the findings from the study contribute to the initiatives like the UN SDG7 that aim to ensure universal access to affordable, reliable, and modern energy by 2030.

2. Approaches of the study

2.1 Description of the study areas

The study focuses on four regions in Ethiopia - Oromia, Southwest Ethiopia, Sidama, and South Ethiopia - examining 13 woredas (districts) and 26 kebeles (villages) from the 22 FOLUR Ethiopia project woredas. These areas were strategically selected due to their diverse agro-ecological conditions, varying socio-economic characteristics, and distinct household energy use patterns, making them representative of settings across Ethiopia's integrated coffee-tree growing landscapes, which creates unique opportunities for integrated energy.

In Oromia region, the study covers five woredas (Kersa, Yayu, Abaya, Dodola, and Chora) across multiple zones, where heavy reliance on traditional biomass (firewood and charcoal) prevails due to high forest resource potential and limited electricity access. Jimma Zone (Kersa) and Illubabor zone (Yayu woredas) serve as one of Ethiopia's primary coffee-producing areas. The area is also known for its cultural and historical significance since it possesses many archaeological and ritual sites (Yayu Forest). It is the largest and most important forest for the conservation of the wild coffee populations in the world. Similar to other parts of the country, agriculture in Yayu area is characterized by smallholder subsistence farming with low productivity (Gole et al. 2008). The dense forests in areas like Yayu, Dodola and Abaya while providing valuable fuel wood and wild coffee resources, face significant deforestation pressures (Beyene et al. 2020), making these locations ideal for piloting integrated energy-coffee initiatives through existing cooperative structures. Households access fuelwood from government forests, community woodlots, and private plantations. While government forests provide legal sources, some unauthorized extraction occurs, particularly near villages. Protected biospheres like Yayu Forest are critical for biodiversity and wild coffee, but nearby communities sometimes harvest fuelwood illegally. Private plantations and on-farm woodlots serve as fully legal sources for household energy self-provisioning.

Southwest Ethiopia's study areas (Shishonde, Gimbo, Guraferda, and Sheybench woredas) demonstrate even heavier reliance on biomass, with majority of households depending on firewood, constrained by limited affordability of alternative energy. This region comprises the Kafa biosphere reserve which is internationally notable due to its ecology, biodiversity, and considerable contribution to the global coffee industry (Befikadu and Kifle, 2018). As the birthplace of Arabica coffee and home to the UNESCO-listed, Kaffa Biosphere Reserve, the region combines high-value coffee production with exceptional biodiversity (Mohammed, 2020). The selection of these woredas by FOLUR project was particularly motivated by the urgent need to address deforestation threats to coffee ecosystems and to develop gender-sensitive energy solutions that reduce the firewood collection burden by the community. Fuelwood is sourced from government forests, community forests, and private plantations, with additional supply coming from degraded or unprotected forest patches. The Kafa Biosphere Reserve is protected for its biodiversity and coffee value, yet illegal collection for fuelwood and charcoal occurs. Private plantations provide a legal, sustainable source for household energy needs.

The Sidama region study sites (Dale and Bensa woredas) present a slightly more diversified energy profile, with high biomass use but growing adoption of electric *injera* stoves in more urbanized kebeles. The region, particularly; Daye Bensa’s coffee is the most valuable cash crop that generates the main livelihood income in the district contributing over 20 million kilos annually and playing a vital role in the country’s export economy (Tadesse and Abayineh, 2022). Despite its high output, farmers face persistent challenges due to inadequate infrastructure, including unreliable electricity, poor telecommunications, and unstable water supply, which hinder profitability and limit growth potential (Growing Coffee, Growing a Community Blog, 2021). Despite its dense population, Sidama’s unique combination of high coffee production, Agroforestry practices, livestock production, and renewable energy potential makes it an ideal location for piloting integrated energy-coffee interventions. Households rely on government and community forests as well as private plantations for firewood. Although legal sources exist, indirect dependence on government forests occurs via market-purchased fuelwood. Illegal harvesting from degraded or unprotected patches has been reported, particularly in densely populated kebeles.

In South Ethiopia's study areas (Yirgachefe and Wenago woredas), energy use patterns show a mix of firewood and charcoal, with promising potential for solar drying technologies to improve coffee processing in highland areas. The Yirgachefe woreda stands out as a global premium coffee hub, achieving high yields of coffee tons/ha through advanced washing station techniques, while Wenago's smaller farms show strong potential for organic certification. The zone's agroforestry systems, which integrate shade trees like Acacia with coffee production (Degefa, 2016; Dilebo, 2019), along with growing ecotourism opportunities, create favorable conditions for renewable energy projects such as solar-powered eco-lodges. Energy needs are met through government forests, community woodlots, and private plantations, with degraded forest patches supplying additional biomass illegally. Protected areas are limited, but unmonitored patches may be exploited. Private plantations and on-farm trees provide a fully legal and sustainable source for household fuel.

The synthesis of selection criteria across all study areas reveals a consistent overreliance on traditional biomass fuels, underscoring the urgent need for renewable energy transitions. These regions also exhibit strong interlinkages between energy use and coffee production, where sustainable energy solutions can enhance both sectors simultaneously. Additionally, their abundant natural resources such as rivers, forests, and organic waste support decentralized energy systems while creating opportunities for gender-inclusive approaches that align with FOLUR Ethiopia's Project priorities. The combined focus on energy and coffee systems in these selected woredas creates a powerful opportunity to develop replicable models for sustainable development that address both household energy needs and agricultural productivity in Ethiopia's most important integrated coffee-tree growing regions (Figure 1).

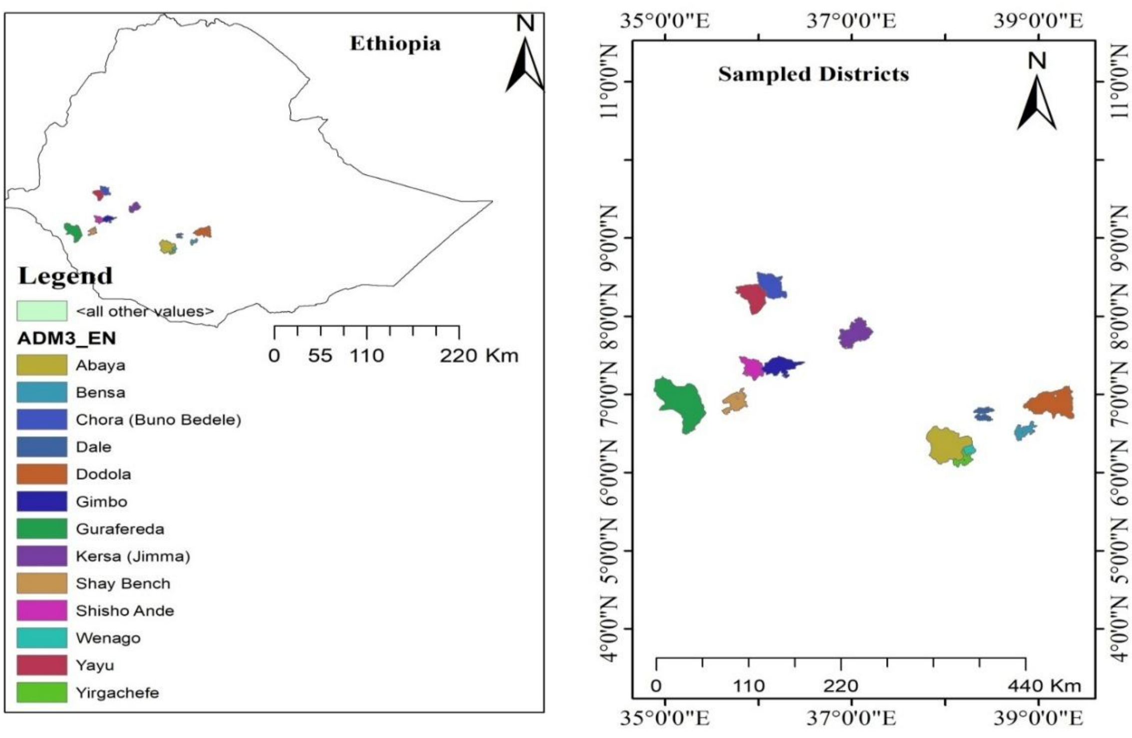


Figure 1 Study area locational map

2.2. Study design and sampling techniques

The study was conducted across 13 Woredas located in the Oromia, Sidama, Southwest Ethiopia, and South Ethiopia regions (Table 1). The study employed a cross-sectional household survey design to assess energy availability, sources, and consumption patterns among communities in FOLUR project areas to ensure representative selection across integrated coffee-tree growing regions. A multi-stage sampling technique was used to ensure representation across different agro-ecological zones and livelihood systems. The intervention areas were stratified by administrative regions and agro-ecological zones. First, FOLUR project intervention regions and zones were identified. Second, 13 Woredas were randomly selected from a total of 22 FOLUR project Woredas proportional to the number of Woredas per zone.

Table 1 Sample of woredas and kebeles from FOLUR Project targeted Regions in Ethiopia

Region	Zone	Sample woreda	Sample kebeles	Sample respondent
Oromia	Jimma	Kersa	Wacho	100
			Folla Gubeta	100
	Ilu Aba Bora	Yayu	Wixate	100
			Bondawo	100
	West Guji	Abaya	Odo Mike	100
			Bunnata	100
	West Arsi	Dodola	Daneba	100
			Kechema	100
	Buno Bedele	Chora	Ale Sardo	100
			Halelu Hadesa	100
Southwest Ethiopia	Kaffa	Shishonde	Dukura Woshi	100
			Agaro	100
		Gimbo	Beyemo	100
			Gawa	100
	Bench Sheko	Guraferda	Ojmeta	100
			Genika	100
		Sheybench	Maz	100
			Bata	100
Sidama	Central Sidama	Dale	Manche	100
			Duba	100
	Eastern Sidama	Bensa	Bonbe	100
			Bensaware	100
South Ethiopia	Gedio	Yirgachefe	Udessa	100
			Wegida	100
		Wenago	Tumata Cirecha	100

	Jemjemo	100
Total		**2,600**
Additional for substitution of non-response and missing data		**37**
Overall sample		**2,637**

Two kebeles were selected from each woreda using stratified random sampling, ensuring representation across the full range of energy use patterns observed in the woreda. First, all kebeles were categorized based on preliminary survey data or secondary information into different energy use strata (e.g., predominantly traditional biomass, mixed fuels, or higher adoption of alternative energy technologies). Then, one kebele was randomly selected from each stratum. This approach captures variation in energy use while minimizing selection bias, ensuring that findings are more generalizable across the woreda.

Finally, 200 household heads were sampled per Woreda using systematic random sampling based on household registration lists from each selected kebele. In total, 2,600 respondents were planned for the survey. To address potential issues of non-response and missing data, an additional 37 respondents were included from Sidama, Oromia and South Ethiopia region, bringing the grand total sample size to 2,637 respondents.

2.3 Data collection methods

The study designed to collect both quantitative data (households' survey) and qualitative data collection through key informant interviews (KIIs) and Focus group discussions (FGDs).

2.3.1. Quantitative data collection

The quantitative data were collected using a structured household questionnaire administered through face-to-face interviews by trained enumerators. Data were collected from a total of 2,637 households across 13 FOLUR project woredas and 26 kebeles in four regions. The data collection was facilitated by trained enumerators using digital data collection tools (e.g., Open Data Kit/ KoboToolbox), which is effective for data management and monitoring. Field enumerators were chosen based on their experience and fluency in speaking the local language. They were trained for one days. The field survey was conducted with close supervision of researchers. The questionnaire was pretested and refined to ensure clarity, cultural appropriateness, and reliability.
The structured household survey questionnaire captured detailed information on:

- Demographics: Gender, age, education, marital status, household composition.

- Livelihood Sources: Types and frequency of income-generating activities (e.g., farming, livestock, off-farm work).
- Land Use: Area of land owned, area allocated to various crops and woodlots.
- Asset Ownership: Types and numbers of livestock and beekeeping equipment owned.
- Types and purposes of energy sources used (e.g., cooking, lighting, heating).
- Quantities consumed and frequency of use.
- Sourcing patterns (e.g., own plantation, communal forests, state forest, markets).
- Travel distance and time for collecting firewood.
- Perceptions and preferences related to alternative energy sources.
- Household energy sources and usage patterns
- Types and duration of use of cookstoves, biogas, and solar technologies
- Motivations for adoption or reasons for non-adoption
- Sources of technology acquisition (market, NGOs, government)
- Challenges faced in access, affordability, durability, and technical operation
- Access and participation in training programs for alternative energy technologies;
- Gender roles in training, procurement, and maintenance;
- Awareness, perception, and sufficiency of the training received;
- Barriers to training access;
- Sources of information on alternative energy technologies;
- Projection of future energy technology demands.

2.3.2. Qualitative data collection

The qualitative data collection was conducted using KII and FGD. It was conducted to complement and enrich the quantitative data after the full report of quantitative data is produced. By combining these approaches, the study was able to capture the underlying reasons behind community energy choices and identify context-specific energy solutions. In each woreda, five KIIs were conducted with local leaders, experts, and community representatives. Additionally, two FGDs were organized per sample woreda, involving representatives from community members, women’s groups, and youth groups, with 8-10 participants in each FGD. This mixed-method approach is designed to provide a comprehensive understanding of both the quantitative and qualitative dimensions of household energy use in the project areas. The KIIs and FGDs followed a semi-structured format, allowing for a combination of guided questions and open-ended discussions to capture a wide range of perspectives. All interviews and discussions were conducted in person to ensure active participation from community members, officials, and experts with substantial institutional knowledge and decision-making roles related to alternative energy solutions (Table 2).

Table 2 Key informant interviews (KIIs) and focus group discussions (FGDs) composition

Stakeholders	Total participants per 13 Woredas	Participants per Woreda
Woreda Water & Energy Office	13 KIIs	1 KII
Woreda Agricultural Office	13 KIIs	1 KII
Woreda Youth & Women's Office	13 KIIs	1 KII
Woreda PFM Officer	13 KIIs	1 KII
Community Representatives	26 KIIs (2 per Woreda)	2 KIIs
Kebele-Level FGDs	26 FGDs	2 FGDs
Total	78 KIIs and 26 FGDs	

2.4. Method of data analysis

Quantitative data were analyzed using Microsoft Excel, SPSS and Stata version 18. Descriptive statistics (frequencies, mean, and percentages) were used to illustrate demographic characteristics, livelihood sources, household energy sources and consumption, adoption rates, usage patterns, sources, and challenges of alternative household energy technologies. Data were also disaggregated by energy technology to compare performance and identify trends. Tables and figures were generated to visualize patterns and support interpretation. A trend analysis was conducted to project future demand for fuel-saving technologies over the next 15 years. The qualitative data collected from KIIs and FGDs were systematically analyzed through thematic analysis to identify key patterns, perceptions, and insights related to household energy use and fuel-saving technologies.

3. Results and discussions

3.1. Demographic profile of respondents

The demographic analysis highlights several important trends in the surveyed population (Table 3). The majority of respondents (74.2%) were men because, men had more time available to participate in surveys, as women were often occupied with household responsibilities, reflecting traditional gender roles. The educational attainment of household heads shows that 24.8% of respondents have no attended formal education while 28.9% of respondents have completed basic education (grade1-4), 30% of them have completed elementary grade (5-8) with only a small proportion (3.2%) have completed over 12 years of education, suggesting limited access to higher education, suggesting limited access to higher education.

Table 3 Demographic profile of the respondents

Variable	Category / Statistic	Frequency	Percent / ± Std. Dev.
Sex of respondent	Female	681	25.8%
	Male	1956	74.2%
Highest level of education	No education	653	24.8%
	Basic (Grades 1–4)	761	28.9%
	Elementary (Grades 5–8)	791	30.0%
	Secondary (Grades 9–12)	312	11.8%
	12+ (Higher education)	85	3.2%
	Other	35	1.3%
Marital Status	Single	19	0.7%
	Married	2498	94.7%
	Divorced	38	1.4%
	Widow	82	3.1%
Age of respondent (years)	Mean	40.59	± 10.92
No. of Male household members	Mean	3.07	± 1.53
No. of Female household members	Mean	3.00	± 1.60

N=represents number of the sample size; Source: Household survey (2024/25)

Additionally, 24.8% of respondents reported having no education, which may indicate socio-economic barriers to accessing education. In terms of marital status, the vast majority of respondents (94.7%) are married, pointing to stable family structures, which may influence energy-related decisions at the household level.

The average age of respondents was 40.59 years with a standard deviation of 10.92, suggesting a predominantly middle-aged group with a moderate age spread. Household composition data shows that, on average, there were 3.07 male members (±1.53) and 3.00 female members (±1.60) per household, indicating relatively balanced gender distribution within households.

3.2. Main livelihood means of sample respondents in the project area

Households in the surveyed area primarily rely on agriculture for their livelihoods, with coffee (79.58%) and cereal crop production (78.78%) being the most common sources of income, followed by livestock farming (52.79%) (Table 4). There is also notable engagement in fruit and vegetable production, indicating some diversification in agricultural activities. While agriculture dominates, other income sources such as wage labor, honey production/beekeeping, and spices provide supplementary earnings. Additionally, petty trading and firewood sales reflect informal, low-barrier activities. However, smaller income sources like handicrafts and oil crops production are less common. Overall, the community's livelihood is predominantly based on agriculture, with limited non-agricultural opportunities, highlighting the need for strategies to diversify incomes, improve education, and support market access.

Table 4 Main means of living for sample households in FOLUR project areas

Means of living	Frequency	Percentage
Coffee	2100	79.58
Cereal crops production	2079	78.78
Livestock	1393	52.79
Fruit crops production	940	35.62
Vegetable production	861	32.63
Other	472	17.89
Pulse crops production	379	14.36
Wage	186	7.05
Honey	144	5.46
Spices	142	5.38
Petty trading	91	3.45
Firewood sales	84	3.18
Retail shopping	47	1.78
Poles or timber	24	0.91
Handicrafts	19	0.72
Oil crops production	5	0.19

Source: Household survey (2024/25)

The statistics show that respondents have a wide range of land sizes, with total land area ranging from 0 to 16 hectares, and an average of 1.48 hectares (Table). The area allocated to woodlots is minimal, with an average of only 0.08 hectares. Cereal crops are the most widely grown crop, covering an average of 0.53 hectares per household, followed by coffee, which averages 0.57 hectares.

Table 5 Summary of land use and crop production

Land holding size (hectare)	Minimum	Maximum	Mean	Std. Deviation
Total area of land	0	16	1.48	1.496
Woodlot owned	0	3	0.08	0.174
Land covered by cereal crops	0	8	0.53	0.684
Land covered by legume (pulse) crops	0	2.5	0.06	0.130
Land covered by oil crops	0	8	0.01	0.161
Land covered by fruit crops	0	8	0.06	0.280
Land covered by coffee	0	14	0.57	0.894
Land covered by tea	0	8	0.01	0.173
Land covered by vegetable crops	0	2	0.05	0.115
Land covered by spice crops	0	8	0.02	0.171

Source: Household survey (2024/25)

Legume (pulse)**,** oil crops**,** fruit crops**,** and vegetable crops all occupy very small portions of land, with average hectares ranging from 0.01 to 0.06. The variability in land allocation for different crops is reflected in the standard deviations, which range from 0.115 (for vegetable crops) to 0.894 (for coffee). This indicates some households may allocate significantly larger portions of land for specific crops, such as coffee. The low average land use for certain crops, like spice crops (0.02 hectares) and tea (0.01 hectares), suggests these are less commonly grown. Overall, this data shows a diverse range of land use practices with a focus on cereal and coffee crops, but minimal investment in other agricultural activities.

The descriptive statistics of livestock and beekeeping assets among the surveyed households reveal notable patterns in ownership and diversity of livelihood sources (

Table). Cattle ownership is widespread, with cows (mean = 1.29) and oxen (mean = 0.96) being the most commonly owned, followed by heifers, bulls & steers, and smaller numbers of sheep (1.16) and goats (0.56). Ownership of equines such as horses (0.16), mules (0.04), and donkeys (0.35) is much less common, indicating their limited role in the local economy. Poultry keeping is relatively significant, with a mean of 2.88 poultry per household, though there’s wide variability as indicated by the high standard deviation (3.961).

Table 6 Livestock ownership

Livestock Assets owned	Minimum	Maximum	Mean	Std. Deviation
Number of oxen	0	10	0.96	1.018
Number of cows	0	12	1.29	1.150
Number of bulls & steers	0	12	0.50	0.818
Number of heifers	0	10	0.71	0.929
Number of sheep	0	32	1.16	1.801
Number of goats	0	20	0.56	1.598
Number of horses	0	8	0.16	0.645
Number of mules	0	8	0.04	0.373
Number of donkeys	0	8	0.35	0.791
Number of poultry	0	100	2.88	3.961
Number of local (traditional) beehives	0	100	8.03	11.254
Number of topbar (transitional) beehives	0	35	1.31	3.870
Number of frame beehives	0	50	1.73	4.940
Number of honeybee colonies	0	75	0.75	3.862
Number of honeybee colonies in local hives	0	75	0.67	3.179
Number of honeybee colonies in topbar hives	0	15	0.14	1.041

Source: Household survey (2024/25)

Beekeeping is practiced to a lesser extent, with only a subset of the households owning local (traditional) beehives (mean = 8.03), top bar (transitional) beehives (mean = 1.31), and frame beehives (mean = 1.73). The average number of honeybee colonies is relatively low (mean = 0.75), with most located in local hives (0.67), while top bar hives host only a small fraction (0.14). The high standard deviations for many of the beekeeping variables reflect considerable differences in scale among the few households that engage in apiculture. Overall, while livestock farming is widespread and moderately diversified, beekeeping remains a niche but potentially scalable activity within the community's livelihood strategy.

3.3. Energy availability, sources, consumption and factors of fuel choice

3.3.1. Energy availability, sources and consumption

The summary of household energy use among 2,637 respondents highlights a heavy dependence on traditional biomass fuels (Table). Drywood emerges as the dominant energy source, used by 94.54% of households for cooking, with a smaller but significant share using it for baking (64.53%) and lighting/heating (23.53%). Although the mean daily usage is high (1.42 person-loads), the median and mode are just 1, indicating that while most households use modest amounts, a few consume excessively, as reflected in the large standard deviation (1.18). Charcoal is used by 12.58% for cooking and smaller proportions for other uses, with moderate mean daily use (2.64 kg) and low variance. Animal dung is used by 8.37% for cooking and 7.81% for baking, but the usage distribution is (1.47 kg/day). Crop residues are widely used (51.65%) for cooking and 36% for baking. In terms of lighting, kerosene is the most common source (36.26%) with highly skewed usage (mean 36.75 liters/month, median 1.8), followed by candles (6.33%) and drywood (23.53%). The small proportion of butagas used for cooking (0.3%) indicates minimal adoption of cleaner energy alternatives. Overall, the data underscores a continued reliance on traditional biomass and minimal penetration of clean energy, with high variability in usage patterns.

These findings are highly relevant to the FOLUR project areas, where energy use is intricately linked to land degradation, forest loss, and unsustainable agricultural practices. The overwhelming reliance on drywood, crop residues, and animal dung for household energy directly contributes to deforestation and soil nutrient depletion, key challenges that FOLUR aims to address through integrated land-use planning and sustainable food systems. The extremely skewed usage data, particularly for drywood and animal dung, suggests unequal access to energy resources and signals the presence of households exerting disproportionate pressure on local ecosystems. The low uptake of clean energy sources like butagas reinforces the need for FOLUR to support energy transition strategies, such as promoting alternative fuels, improving cookstove technologies, and facilitating access to renewable energy. Moreover, the project's focus on land restoration and climate-smart agriculture can be strengthened by addressing energy needs in tandem, ensuring that livelihoods, forest conservation, and energy access are improved in a coordinated, sustainable manner across project landscapes.

Table 7 Summary of household energy use types and consumption

Energy Source	Usage Purpose	Users (n)	% of Total	Quantity Used	Mean	Median	Mode	Std. Dev.
Drywood	Cooking (including baking and lighting)	2495	94.54	Per day (person-loads)	1.1	1.00	1.00	1.18
	Baking	1703	64.53		–	–	–	–
	Lighting/Heating	621	23.53		–	–	–	–
Charcoal	Cooking	332	12.58	Per day (kg)	2.64	1.00	1.00	1.58
Animal Dung	Cooking	221	8.37	Per day (kg)	1.47	1.00	2.00	1.02

	Baking	206	7.81		–	–	–	–
	Lighting/Heating	6	0.23		–	–	–	–
Crop Residues	Cooking	1363	51.65	–	–	–	–	–
	Baking	950	36.00		–	–	–	–
	Lighting/Heating	415	15.73		–	–	–	–
Candle	Lighting (assumed)	167	6.33	Per month (pieces)	9.08	6.00	5.00	8.15
Kerosene	Lighting/Heating	957	36.26	Per month (litres)	36.75	1.80	1.00	33.75
	Cooking (butagas use)	8	0.30		–	–	–	–

Source: Household survey (2024/25)

By linking these insights with the FOLUR project's broader land-use and restoration goals, this data enables targeted interventions to promote energy diversification, reduce environmental impact, and enhance community resilience. Therefore, the current usage patterns provide a foundational baseline for identifying viable alternative household energy sources and adapting sustainable energy strategies in the project region.

Table presents the distribution of household energy sources across the FOLUR-implemented regional states. Drywood (including branches and leaves) was the most widely used energy source, with 97.5% of households reporting its use, and usage was relatively consistent across regions, ranging from 95.6% in Sidama to 98.1% in Oromia ($\chi^2 = 7.990$, $p = 0.046$). Charcoal was used by 13.5% of households overall, with the highest use in South West Ethiopia (17.5%) and the lowest in South Ethiopia (0.7%), showing a significant regional variation ($\chi^2 = 73.133$, $p < 0.001$).

Animal dung was less commonly used, reported by 8.5% of households overall, with Oromia having the highest use (19.6%) and minimal use in Sidama and South Ethiopia (1.2% and 0.5%, respectively), again differing significantly by region ($\chi^2 = 263.420$, $p < 0.001$). Crop residues were used by 55.8% of households, with the highest proportion in Oromia (68.7%) and lowest in Sidama (33.9%) ($\chi^2 = 160.230$, $p < 0.001$). Candle use was relatively low (6.3% overall), with South Ethiopia showing the highest usage (11.4%) ($\chi^2 = 49.774$, $p < 0.001$). Kerosene usage varied dramatically, with 36.4% of households overall using it, highest in South Ethiopia (84.4%) and Sidama (64.1%) and very low in South West Ethiopia (0.7%) ($\chi^2 = 990.968$, $p < 0.001$). These results indicate significant regional differences in household energy source preferences.

Table 8 Distribution of energy sources by FOLUR implemented regional states

Energy Source	Oromia		Sidama		South Ethiopia		South West Ethiopia		Total		Chi-Square	p-value
	n	%	n	%	n	%	n	%	n	%		
Drywood (branches & leaves)	992	98.1	392	95.6	399	97.1	787	97.8	2570	97.5	7.990	0.046***
Charcoal	160	15.8	53	12.9	3	0.7	141	17.5	357	13.5	73.133	0.000***
Animal dung	198	19.6	5	1.2	2	0.5	18	2.2	223	8.5	263.420	0.000***
Crop residues	695	68.7	139	33.9	195	47.4	443	55.0	1472	55.8	160.230	0.000***
Candle	25	2.5	26	6.3	47	11.4	68	8.4	166	6.3	49.774	0.000***
Kerosene	343	33.9	263	64.1	347	84.4	6	0.7	959	36.4	990.968	0.000***

*Note: ***, ** and * represents statistical significance at 1%, 5% and 10% probability level, respectively.*

Source: Household survey data analysis results (2024/25)

A significant majority of households (72.57%) reported collecting dry wood from their own plantations, indicating considerable engagement in small-scale energy self-provisioning (Figure 2). However, the reported reliance on community forests (31.91%) and government forests (16.75%) still reflects notable dependence on common and public natural resources. While the percentage reporting direct collection from government forests appears relatively modest, qualitative evidence from FGDs and KIIs confirms that many households also obtain fuelwood and charcoal through local markets, where supplies frequently originate from nearby government-managed or natural forests.

These findings are consistent with previous studies in Ethiopia showing that even when households report purchasing biomass fuels or sourcing from private lands, the supply chain often traces back to natural or state forests (Mekonnen & Köhlin, 2008; Gebreegziabher et al., 2010; Alem et al., 2014; Azanaw & Melaku, 2023). Therefore, although private plantation sourcing appears dominant, both direct and indirect reliance on community and government forests remains significant, with important implications for forest sustainability and forest degradation pressure.

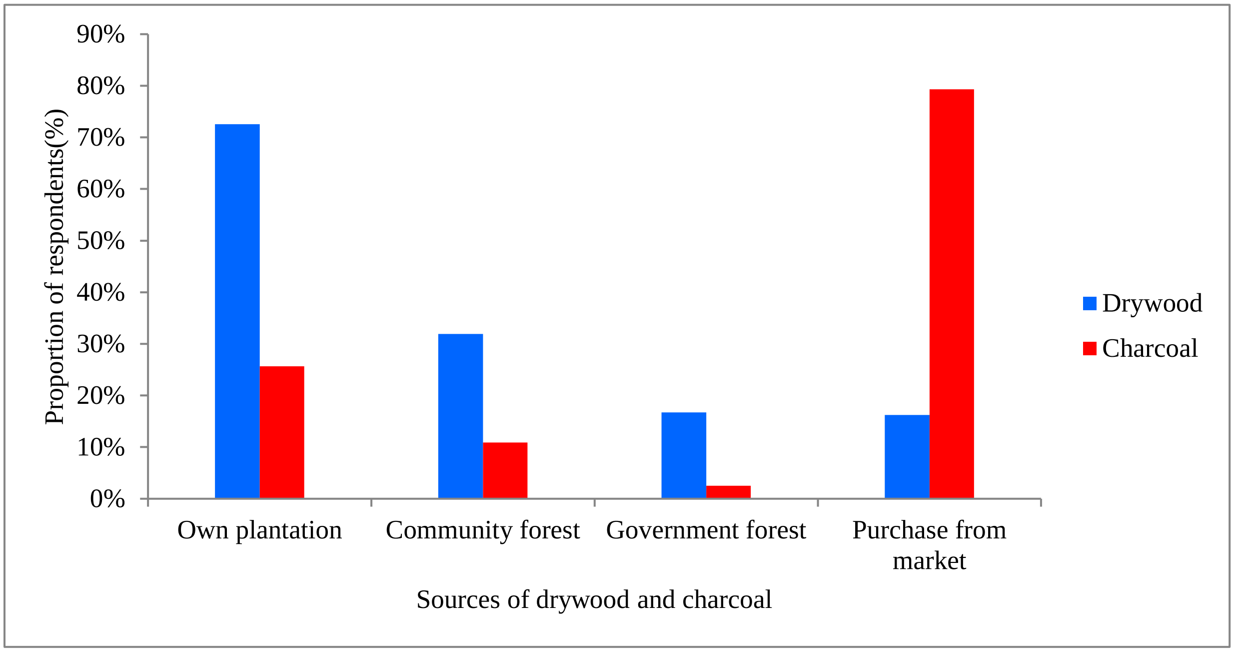


Figure 2 Drywood and charcoal production for household energy needs

Source: Household survey (2024/25)

Charcoal, in contrast, is primarily acquired through market purchase (79.33%), showing its more commercialized nature and potentially higher economic burden on users. Only a small proportion of households (25.68%) source charcoal from their own plantations, while some proportion of them from communal/government forests. Group participants across most study districts said that, charcoal is purchased from local markets followed by from private woodlots/plantations, community forest and government forests. The FGD participants further stated that charcoal production from community forest and government forest contributes to continous forest degradation.

This supports the need for the FOLUR project to focus not only on introducing alternative energy technologies but also on improving the sustainability of existing biomass sourcing. Promoting agroforestry, community woodlots, and regulated access to forest resources, alongside improved cookstoves or clean fuel initiatives, could be key strategies. Thus, this data not only categorizes existing sources but also pinpoints strategic entry points for enhancing household energy sustainability in line with FOLUR's integrated landscape and livelihood goals.

The data on firewood collection reveals critical insights into the accessibility of household energy sources in the FOLUR project regions (Figure 3). Among the 2,572 respondents who answered, nearly half (48.39%) reported that firewood sources are located less than one kilometer from their homes, which suggests relatively easy access for a significant portion of the population. However, a substantial number of households (32.85%) travel 1 to 3 kilometers, and an additional 12.43% travel 3 to 5 kilometers indicating increasing time and labor costs, especially for women and children, who often bear the burden of fuelwood collection. Notably, a smaller but concerning segment of respondents reported traveling long distances: 3.26% go 5 to 10 kilometers, and some even travel over 10 kilometers (0.53%). The few households traveling more than 20 kilometers (0.08%) highlight extreme cases of resource scarcity, potentially leading to environmental degradation in distant areas and reinforcing the urgency of energy alternatives.

This result is supported by qualitative result as women and young children often travel long kilometers to collect fuel wood. This not only limits time for other productive tasks but also contributes to fatigue and reduced participation in social and economic life. These findings further reinforce the importance of the FOLUR project's objective to identify and promote alternative household energy sources. Long distances for firewood collection not only signal unsustainable pressure on nearby forests but also reflect inequitable energy access. Integrating energy-efficient technologies like improved cookstoves, establishing local community woodlots, and promoting alternative fuels such as biogas or solar energy could mitigate these burdens and support both household well-being and landscape sustainability.

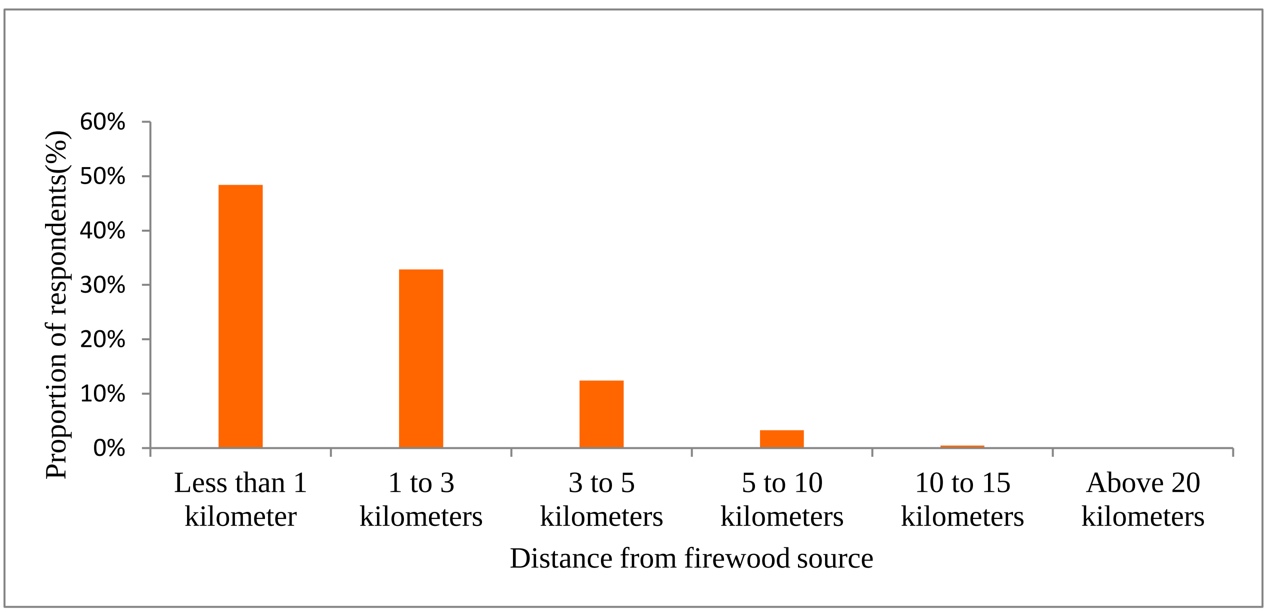


Figure 3. Distance from residence to firewood collection site

Source: Household survey (2024/25)

3.3.2 Social, environmental and health challenges associated with biomass fuel dependence

Gender and social dimensions

Traditional biomass energy systems continue to impose disproportionate burdens on women and girls, who bear the primary responsibility for cooking and firewood collection across all regions. The result reveal that, in the southwestern region, Gedeo, and parts of Oromia, women typically spend 1–2.5 hours daily walking long distances to collect firewood from forests or communal lands, often in degraded or restricted areas. These findings are consistent with related studies (FAO, 2019; Parikh, 2011), which reported that women and children spend extended hours walking over hilly and high-altitude terrain to collect firewood, often facing health and safety risks. Focus group discussions from Abaya and Yirgachefe Woredas revealed that "the heavy workload of firewood collection from forests and bushlands exposes women to physical strain, thorn injuries, back pain, and harassment, while also limiting their participation in education, income-generating activities, and community leadership. The study confirms that women are mainly responsible for fuel collection; thus, their time allocation to other productive and social activities is more constrained than men's (Scheurlen, 2015). This situation reinforces gender inequality and perpetuates women's limited opportunities for social and economic advancement.

Environmental impact

The KIIs and FGD participants stated that the use of traditional biomass fuels mainly firewood and charcoal still contribute forest degradation, and biodiversity loss across the study regions. Results obtained from qualitative data showed that, participants from all woredas repeatedly described how the growing demand for household energy has placed unsustainable pressure on surrounding government and community forest. Experts from Yayu and Wonago districts explained that *"the natural forest cover controlled under government is shrinking year after year because every household depends on firewood; even fallen branches are no longer enough, so people cut live trees to meet daily energy needs."*

Similarly, group discussants from Dodola, Abaya, Guraferda and Shey benchi reported that unregulated firewood and charcoal production have *been the primary driver of* *deforestation near the past years*. The degradation of forest resources has also intensified soil erosion and watershed decline. Declining vegetation cover exposes the soil to erosion and increases surface runoff, which reduces soil fertility and accelerates sedimentation in nearby rivers and springs (Ouyang et al., 2010).

Group discussants from Gedeo and Sidama observed that "*after the trees were cleared for fuelwood, our farmland started washing away during the rainy season, and streams that used to flow all year now dry up by* mid-*summer*." This indicates firewood collection contributes for deforestation. The process not only diminishes biodiversity but also disrupts the ecological functions of forest ecosystems, including soil stabilization and microclimate regulation. As one NRM expert from Dale Woreda of Sidama region said that, "*the more trees we lose, the hotter and drier our area becomes; even coffee no longer grows the way it used to because the microclimate has changed*." These findings reveal that the environmental impacts of traditional biomass energy use extend far beyond fuel scarcity they threaten the very ecological balance that supports rural livelihoods and agricultural systems.

Health Impacts

Traditional cooking practices have also generated public health consequences across all study regions. Women and children, who spend long hours in poorly ventilated kitchens, are the most affected by indoor air pollution (Dasgupta et al., 2006; Deepthi et al., 2019; Dida et al., 2022). The most frequently cited issue is health problems caused by indoor air pollution. Participants specifically reported "smoke-related health issues," including respiratory illnesses, coughing, and eye problems, predominantly affecting women and children who spend the most time near the cooking area. Experts from Sidama and Gedeo explained that prolonged exposure to smoke from traditional stoves causes chronic respiratory illnesses, eye irritation, persistent coughing, and frequent headaches. In focus group discussions held in almost all regions (study areas), participants described how the use of open fires and unstable cooking setups leads to repeated accidents and injuries. 'W/ro Almaz' from Bansa District recounted that *"our children often fall into the fire while playing near the cooking area because there is no proper stove or separation from the living space."* Other participants added that burns are common, particularly among toddlers who crawl near open flames. Such experiences highlight the unsafe conditions under which many rural households prepare their food.

3.3.3. Factors affecting household fuel choice in FOLUR Ethiopia project areas

Firewood/dry wood choice

Sex of household: Sex of the household head has a positive and statistically significant effect on firewood use (Table). Male-headed households are more likely to rely on firewood compared to female-headed households. This may reflect men's greater control over household decision-making and access to labor or land resources, which facilitate firewood collection. Similarly, Gebreegziabher et al. (2018) found that households headed by men generally report higher biomass fuel consumption, reflecting both resource control and decision-making authority. At the same time, prior sections show that women and children bear the primary physical burden and time costs of collecting firewood, particularly from distant sources. These findings highlight different dimensions of the issue: while male-headed households report greater use and preference for firewood due to control over resources, female-headed households may be more likely to seek alternative fuels when firewood is scarce or collection is labor-intensive.

Education status: Education negatively influences the choice of firewood as a primary fuel source. Households with better-educated heads are less likely to rely on firewood. Education enhances awareness of the environmental consequences of deforestation and the health hazards of indoor smoke exposure from traditional wood stoves. It also broadens opportunities for employment and income, enabling the adoption of cleaner or more efficient fuels. Thus, literacy and awareness campaigns promoting sustainable energy use are essential in forest-dependent communities.

Distance from firewood source: The multivariate probit model (MVP) model results show that distance to firewood sources is statistically significant at less 1% probability level, and a major determinant of firewood use.

Table 9 Multivariate probit model estimation results

Variable	Firewood choice	Charcoal choice	Animal dung choice	Crop residue choice
Sex	0.263 *	0.016	0.295**	-0.256***
	(0.140)	(0.079)	(0.091)	(0.060)
Age	0.002	0.010***	0.003	-0.004*
	(0.006)	(0.003)	(0.004)	(0.002)
Education status	-0.429*	0.750***	0.721***	-0.336*
	(0.330)	(0.196)	(0.223)	(0.182)
Marital status	0.217	0.477**	0.598**	-0.166
	(0.241)	(0.192)	(0.260)	(0.117)
Female household members	0.00005	-0.028	-0.019	0.026
	(0.064)	(0.034)	(0.038)	(0.026)
Total family size	0.043	0.043**	*0.117****	-0.005
	(0.043)	(0.022)	(0.025)	(0.017)

Variable	Firewood choice	Charcoal choice	Animal dung choice	Crop residue choice
Land owned	0.187 (0.288)	0.378 (0.296)	-0.235 (0.255)	0.011 (0.166)
Beehive owned	0.072 (0.181)	-0.111 (0.092)	-0.322** (0.130)	0.079 (0.070)
Separate kitchen owned	*0.782**** (0.118)	*0.361**** (0.082)	*0.449**** (0.110)	*0.249**** (0.056)
Distance from firewood source	*-1.101 **** (0.157)	*0.299 **** (0.066)	*0.911**** (0.097)	0.148*** (0.050)
_cons	*1.455* (0.410)	*-2.974* (0.375)	*-3.597* (0.390)	0.212 (0.217)

*Note: ***, **, and * represent statistical significance at 1%, 5%, and 10%, respectively. Numerical values in brackets are standard errors.*

Source: Household survey (2024/25)

The negative and highly significant coefficient indicates that households located farther from forests are much less likely to use firewood. The greater the distance, the higher the time and labor costs required for fuel collection. This limitation pushes households to switch to alternative sources such as charcoal, dung, or crop residues. The result underscores the direct link between forest accessibility and dependency on wood fuel, implying that forest degradation could gradually drive a shift toward other energy types in the study areas.

Charcoal choice

Age of household: Age has a strong positive effect on charcoal use. Older household heads are more likely to rely on charcoal compared to younger ones. This may reflect experience-based preferences for fuels that are cleaner and easier to handle than raw firewood. Charcoal's convenience, especially in urban or peri-urban settings, might also appeal to older individuals who prioritize comfort and reduced physical labor in fuel collection.

Education status: Education is positively and significantly related to charcoal use. Unlike firewood, charcoal is often purchased rather than collected/produced, and households with better education and income can afford to buy it. Educated individuals may also perceive charcoal as a "modern" or cleaner fuel compared to traditional biomass, even though its production can contribute to deforestation. This finding indicates that higher education, while reducing raw firewood dependence, may shift households toward commercially available but still biomass-based fuels.

Marital status: Married individuals are significantly more likely to use charcoal. Marriage often increases household size and income pooling, making the purchase of charcoal more feasible. In addition, married households may prefer charcoal due to its controllability and suitability for preparing a wider variety of meals, particularly in larger families.

Total family size: Larger households are more likely to use charcoal as their main energy source. This may be because of the need for more efficient and faster cooking options when preparing meals for many members. Larger families might also require higher energy inputs, making charcoal, an energy-dense fuel, more practical than crop residues or dung.

Separate kitchen ownership: Having a separate kitchen significantly increases the likelihood of using charcoal. Separate kitchens often indicate better housing conditions and higher socio-economic status. Charcoal's clean-burning characteristics make it suitable for enclosed cooking spaces, aligning with the lifestyle of better-off households.

Distance from firewood source: The positive and significant coefficient for distance to firewood sources suggests that households farther from forests tend to substitute firewood with charcoal. This substitution effect reflects the adaptation of households to fuel scarcity. Charcoal is easier to transport and store than raw firewood, making it a preferred alternative when forest resources are less accessible.

Animal dung choice

Sex of household: Sex of the household head significantly influences the use of animal dung as a fuel source. Male-headed households are more likely to use dung, possibly due to their greater involvement in livestock management, which provides easier access to this resource. This aligns with findings by Mekonnen and Köhlin (2008), who reported that male-headed households with larger livestock holdings tend to use more dung as fuel. Similarly, studies in rural Ethiopia indicate that while female-headed households may collect dung for household use, male-headed households generally utilize greater quantities of dung for both fuel and manure, reflecting their higher livestock ownership (Fekadu et al., 2024; Gebreegziabher et al., 2018). These patterns demonstrate that household gender dynamics, combined with livestock assets, strongly influence the use of dung as an energy source.

Education status: Contrary to expectations, education has a positive and significant effect on animal dung use. This may be due to awareness among educated farmers of the multiple uses of dung, including its role as both fuel and fertilizer. Educated households may also be more innovative and willing to process dung efficiently, such as through drying or briquetting. However, the environmental and health implications of dung burning, such as indoor pollution, remain concerns that require targeted awareness campaigns. The finding that education reduces reliance on firewood while increasing the likelihood of charcoal use resonates with the energy stacking model, where education facilitates a shift towards more convenient, purchased fuels without a complete abandonment of biomass (Guta, 2020).

Total family Size: Larger families are significantly more likely to rely on dung fuel. As family size increases, the need for affordable and accessible energy rises. Dung provides a no-cost fuel source for low-income households, especially in areas where firewood is scarce or costly. This relationship highlights the vulnerability of large households to energy poverty.

Beehive ownership: Beehive ownership is negatively associated with dung use. Beekeeping households tend to be more conservation-oriented, valuing forest preservation and environmental sustainability. Since dung burning contributes to pollution and affect bee colony in the backyard beehives, these households may avoid using it as a primary energy source.

Separate kitchen ownership: Households with a separate kitchen are more likely to use animal dung. The availability of a designated cooking area allows for better management of smoke and odor from dung combustion. This indicates that while dung is a low-cost energy source, its use is facilitated by adequate household infrastructure.

Distance from firewood source: Distance to firewood sources strongly and positively influences dung use. As households move farther from forest resources, they increasingly substitute dung for firewood. This underscores the adaptive behavior of households facing resource constraints and the crucial role of proximity to natural forests in determining energy strategies.

Crop residue choice

Sex of household: The negative and highly significant coefficient suggests that female respondents are less likely to use crop residues as their main fuel. Men may favor residue burning as a convenient disposal method after harvest, while women, typically responsible for cooking may prefer other fuels that are easier to handle or more efficient. Additionally, women may recognize the agricultural value of crop residues as soil cover or livestock feed, reducing their likelihood of using them as fuel.

Age of household: Age negatively affects the use of crop residues. Older individuals tend to rely on traditional fuels like firewood or dung due to familiarity, while younger households may be more with residues or other alternatives. This indicates a generational difference in energy practices within rural communities.

Education status: Education reduces the probability of using crop residues as fuel. Educated individuals are more aware of the agronomic value of residues in improving soil fertility and preventing erosion. Consequently, they prefer to retain residues for agricultural use rather than burning them. This finding reinforces the positive link between education and sustainable resource management.

Separate kitchen ownership: Households with separate kitchens are significantly more likely to use crop residues as fuel. Separate kitchens make it easier to handle bulky residues and manage smoke, making this practice more feasible. However, this may also reflect the pragmatic use of available resources in farming households with well-organized living spaces.

Distance from firewood source: Distance to firewood sources positively influences crop residue use. As access to forests diminishes, households turn to agricultural by-products as substitute fuels. This adaptive strategy is common in forest-dependent areas facing fuelwood shortages. However, excessive residue burning can compromise soil fertility, highlighting the trade-off between energy security and agricultural sustainability.

Correlation estimates of multiple fuel choices

The multivariate probit model simultaneously estimated the likelihood of using four major household fuels firewood, charcoal, animal dung, and crop residues allowing for interdependence among their choices (Table). The correlation coefficients (ρ values) capture the relationship between unobserved factors affecting each fuel choice.

Statistically significant correlations indicate that the choices are not independent, meaning households often rely on multiple fuels ("fuel stacking") or substitute one fuel for another depending on access, cost, and environmental constraints.

Table 10 Correlation estimates of multiple fuel choices by MVP model

Parameter		Coefficient	Std. Err.	z	P > z
/atrho21		-0.036	0.057	-0.63	0.528
/atrho31		0.034	0.064	0.53	0.599
/atrho41		0.150	0.048	3.11	0.002
/atrho32		*0.586*	0.052	11.15	0.000
/atrho42		*-0.460*	0.038	-12.23	0.000
/atrho43		*-0.472*	0.043	-10.97	0.000
rho21		-0.036	0.057	-0.63	0.527
rho31		0.034	0.064	0.53	0.599
rho41	Firewood and crop residue	0.149	0.047	3.16	0.002***
rho32	Charcoal and animal dung	*0.527*	0.038	13.88	0.000***
rho42	Charcoal and crop residue	*-0.430*	0.031	-14.03	0.000***
rho43	Animal dung and crop residue	*-0.440*	0.035	-12.67	0.000***

Source: Household survey (2024/25)

Significant correlations

Firewood and crop residue

The positive and significant correlation between firewood and crop residue use implies a complementary relationship. Households that use firewood are also likely to use crop residues as supplementary fuel. This pattern reflects the common practice of fuel stacking, where rural households combine multiple biomass sources to meet cooking energy needs. Crop residues may serve as backup fuel when firewood becomes scarce or during the agricultural harvest season when residues are readily available. This interdependence demonstrates that energy substitution in forest-dependent communities is not complete, instead, households diversify fuel use to ensure energy security.

Charcoal and animal dung

A strong positive correlation exists between charcoal and animal dung use. This suggests that households using charcoal are also likely to use dung, reflecting partial complementarity between purchased and locally available fuels. One interpretation is that while charcoal is convenient for quick cooking, animal dung serves as a no-cost backup fuel for longer cooking sessions or when household income is limited. This dual usage underscores the importance of economic flexibility in energy decisions, as households manage trade-offs between convenience and affordability.

Charcoal and crop residue

The negative and significant relationship between charcoal and crop residue choices indicates substitution between these two fuels. Households that rely heavily on charcoal are less likely to use crop residues. Charcoal is a relatively cleaner and higher-energy fuel, often purchased by households with higher income levels, while crop residues are used mainly by poorer or resource-limited households. This inverse relationship highlights the income gradient in fuel choice, where wealthier households' transition toward commercial fuels while poorer households depend on agricultural by-products.

Animal dung and crop residue

There is a strong negative correlation between animal dung and crop residue use, implying that these two fuels act as substitutes. Both are non-woody biomass fuels derived from agricultural activities, and households typically choose one based on resource availability. For example, livestock-owning households prefer dung, while crop farmers without livestock rely more on residues. This substitution pattern indicates a livelihood-based differentiation in fuel use, driven by household resource endowments livestock versus crop production.

Interpretation and implications

The correlation results collectively reveal a pattern of fuel stacking and partial substitution among forest-dependent households in Ethiopia's FOLUR project areas. Complementary relationships (e.g., firewood with crop residues, charcoal with dung) indicate that households diversify energy sources to maintain resilience against supply fluctuations. Substitution effects (e.g., charcoal vs. crop residues, dung vs. crop residues) show how economic status and resource availability influence household energy transitions.

These findings highlight that rural energy use is not linear or unidirectional. Even as some households adopt commercial fuels like charcoal, traditional biomass remains integral due to affordability and accessibility. The observed complementary and substitution relationships among different fuels confirm that rural households engage in fuel stacking rather than following a simple 'energy ladder' pathway. This finding challenges the linear transition model and is strongly supported by a growing body of literature in Sub-Saharan Africa, which shows that households strategically use multiple fuels to meet different needs, manage risk, and cope with fluctuating income and resource availability (van der Kroon et al., 2013; Masera et al., 2000). The evidence supports the energy ladder and energy stacking models, emphasizing the coexistence of traditional and modern fuels rather than a complete transition. From a policy perspective, promoting fuel-saving technologies such as improved stoves and biogas systems could help reduce reliance on unsustainable biomass combinations. Additionally, efforts to improve access to renewable energy options like solar systems should consider the existing interdependence of fuel types. Addressing these dynamics can strengthen household energy security while mitigating deforestation and land degradation in the FOLUR project areas.

3.4. Local production potential and market availability of alternative household energy technologies.

3.4.1. Improved Cookstoves (ICS)

The findings reveal a substantial gap in the adoption of clean energy technologies across the project areas, with just 10.99% of respondents using improved (fuel-efficient) cook stoves (Table 4). The findings suggest a significant opportunity for the FOLUR project to intensify its interventions in promoting sustainable household energy solutions.

Table 4 Household adoption and usage patterns of ICSs in FOLUR project intervention areas

Alternative energy type	Response	Frequency	Percentage
Usage of improved (fuel-efficient) cookstove	No	2349	89.01
	Yes	290	10.99
Purpose of cookstove use in the household	Cooking	279	48.02
	Baking	210	36.21
	Lighting or heating	4	0.69
Length of time using improved cookstove in the household	In the last 1-3 years	89	30.69
	Since more than five years ago	87	30.00
	In the last 3-5 years	76	26.21

Alternative energy type	Response	Frequency	Percentage
	Since less than a year	38	13.10

Source: Household survey (2024/25)

Results from KIIs emphasized that local production capacity for improved cookstoves is very limited. Artisans in rural woredas often lack access to essential materials such as cement and metal sheets, resulting in low-quality stoves that are fragile and prone to cracking within months. Most production remains informal and unstandardized. Respondents identified cooperative-based production, especially involving women and youth, as a viable solution to increase supply, ensure quality, and enhance local ownership. As one woreda energy expert noted, "If women's groups can produce and sell stoves locally, it will solve both employment and fuel problems." However, experts agreed that these cooperatives require technical training, financial support, and institutional backing to be sustainable.

Given that 89.01% of households still depend on traditional cooking methods, which are typically inefficient and environmentally harmful, there is considerable potential for the FOLUR initiative to reduce pressure on forest resources by scaling up the dissemination and affordability of fuel-efficient cookstoves.

In line with FOLUR's objectives to enhance land restoration and climate resilience through sustainable food and land-use systems, promoting clean cooking technologies directly supports ecosystem protection. The current use of cookstoves is primarily for cooking (48.02%) and baking (36.21%), which indicates that interventions must ensure that the improved stoves are not only efficient but also culturally and functionally suitable for local cooking and baking practices.

The data on the duration of use also provides insights into adoption patterns: some of households have been using improved cookstoves for over three years, while 13.10% are recent adopters. This trend suggests a growing but gradual acceptance, underscoring the need for FOLUR to strengthen community engagement, demonstration, and awareness campaigns. Prioritizing these interventions in areas with the lowest adoption could significantly contribute to FOLUR's broader goals of reducing deforestation, improving household health, and advancing sustainable livelihoods.

Across the surveyed regions, the use of improved fuel-efficient cookstoves varies considerably at the woreda level (Table 5). In West Arsi, the woreda of Dodola shows high distribution, with 74.9% of households using improved cookstoves, in contrast to the overall woredas' lower distribution. Similarly, in Illu Ababor, Yayu has a notably distribution (35.8%) compared to the woredas' average.

Conversely, several woredas report very low distribution of improved cookstoves. In Jimma (Kersa) and Eastern Sidama (Bensa), no households reported having access to these stoves, indicating that the technology may not have been adequately supplied or introduced in these areas. Other woredas, such as Chora in Buno Bedele and Shishonde in Kaffa, show minimal distribution rates of 2.5% and 1.5%, respectively. These figures may partly reflect the recent introduction of improved cookstoves in these woredas, suggesting that limited exposure time, rather than lack of interest, could account for low presence. Improving distribution networks and ensuring timely availability are therefore critical for expanding coverage across underserved regions. Moderate distribution is observed in a few areas, such as Guraferda in Bench Sheko (8.9%) and Yayu in Illu Ababor (35.8%). These woredas highlight opportunities for targeted interventions, such as awareness campaigns or subsidy programs, to increase the use of improved cookstoves. Overall, while some woredas demonstrate encouraging uptake, many remain far below national or regional targets, emphasizing the need for localized strategies to wider distribution.

Table 6 Distribution of improved cookstoves across target woredas

Zone	Woreda	No		Yes	
		N	%	N	%
West Arsi	Dodola	51	25.1	152	74.9
West Guji	Abaya	192	94.6	11	5.4
Jimma	Kersa	200	100.0	0	0.0
Illu Ababor	Yayu	129	64.2	72	35.8
Buno Bedele	Chora	199	97.5	5	2.5
Kaffa	Gimbo	186	93.0	14	7.0
Kaffa	Shishonde	198	98.5	3	1.5
BenchSheko	Guraferda	184	91.1	18	8.9
BenchSheko	Shay Bench	200	99.0	2	1.0
Gedio	Wenago	202	98.5	3	1.5
Gedio	Yirgachefe	200	97.1	6	2.9
Central Sidama	Dale	203	99.0	2	1.0
Eastern Sidama	Bensa	205	100.0	0	0.0

Source: Household survey (2024/25)

The motivations for adopting improved cookstoves among respondents in the FOLUR project areas are multifaceted, with practical benefits taking precedence (**Error! Reference source not found.**). The most commonly cited reason by user households was firewood saving (16.65%), indicating that users are highly motivated by the opportunity to reduce fuel consumption an important outcome aligned with forest conservation goals. This is closely followed by time saving (15.55%) and health benefits

(15.43%), suggesting that users also value the efficiency and potential to reduce indoor air pollution associated with traditional stoves. Environmental benefits (14.56%) and cost savings (14.27%) also featured prominently, reflecting an awareness of broader ecological and economic gains. Other reasons included simplicity of use (13.69%) and improved food taste (7.89%), indicating practical satisfaction and cultural alignment with improved stoves. Only a small fraction adopted the technology due to subsidies (1.44%) or other unspecified reasons (0.52%), suggesting that intrinsic motivations outweigh financial incentives. These findings highlight the importance of emphasizing multiple co-benefits especially fuel, time, and health savings when promoting improved cookstoves in FOLUR intervention strategies.

Table 7. Motivations for using improved cookstoves among users in FOLUR Project Areas

Reason	Frequency	Percentage
Firewood saving	287	16.65
Time saving	268	15.55
Health benefit	266	15.43
Environmental benefit	251	14.56
Cost saving	246	14.27
Simplicity	236	13.69
Food taste	136	7.89
Because of subsidies	21	1.44
Other	9	0.52

Source: Household survey (2024/25)

Among 2637 surveyed households, only 355 (13.46%) of households were improved stove users (Table 8). Among improved stove users, mirt stove is the most widely used improved cookstove type among households in the FOLUR project areas, accounting for 70.25% of users (Table 1**4**). This suggests a strong preference for the Mirt stove, likely due to its suitability for traditional baking (e.g., injera), fuel efficiency, and local availability. The Mirchaye stove follows distantly at 17.57%, while all other stove types including Tikikil, Gonzye, Lakech, and biogas or other stoves have adoption rates below 4%. This shows that traditional stoves are still used by majority of households, reflecting a need for continued efforts to transition all households to improved energy technologies.

Table 9 Types of cookstoves used by households in FOLUR project areas

Stove Type	Frequency	Percentage
Mirt	248	70.25
Mirchaye	62	17.57
Tikikil	12	3.40
Traditional stove	12	3.40
Gonzye	9	2.55
Lakech	7	1.98
Biogas stove	2	0.57
Other	3	0.85

Source: Household survey (2024/25)

The results reveal both user challenges and adoption barriers that hinder the wider use of fuel-saving cookstoves in the FOLUR intervention areas (Table). Among existing users, limited durability (**34**.14%) and technical complexity (19.31%) are prominent problems, suggesting concerns about product quality and ease of use. High maintenance costs (11.38%) and space requirements (6.55%) were less frequently cited but still notable. Interestingly, 42.07% reported lack of local supply/production.

For non-users, the dominant reason for non-adoption of fuel-efficient cookstoves was limited awareness (78.1%), highlighting a critical gap in outreach and information dissemination. This suggests that increasing knowledge about the benefits and availability of these technologies is essential for promoting wider adoption. Other important barriers included limited availability (71.6%), reflecting supply chain and distribution challenges in rural or underserved areas, as well as high purchasing costs (47.7%) and limited access to finance (43.6%), which point to affordability constraints. These findings underscore the need for targeted interventions that prioritize raising awareness, while also improving accessibility, affordability, and product reliability to ensure sustained and widespread adoption of fuel-efficient cookstoves across FOLUR project sites. Results from both FGDs and KIIs show that adoption of ICS in forest-dependent communities faces multiple, interconnected challenges. Technical issues including fragile designs, poor fit for traditional cooking practices, and lack of maintenance services lead to short stove lifespans and user frustration. Financial barriers such as high costs, absence of credit or subsidies, and concentration of sales in urban centers limit affordability and access for remote households. Sociocultural factors, including preferences for traditional cooking methods, male-dominated decision-making, and perceptions of ICS as “town technology,” further reduce uptake. Kitchen and design constraints, such as small, poorly ventilated spaces and multi-use cooking areas, limit stove usability. Institutional weaknesses, including fragmented coordination among government offices, donor-driven projects without continuity, and lack of quality standards, undermine program sustainability. Environmental and logistical barriers, such as poor roads, rugged terrain, seasonal rains, and limited raw materials, exacerbate these challenges. Low local production capacity and informal, unstandardized supply chains further restrict availability. Participants suggested that supporting local cooperative production particularly involving women and youth—combined with technical training, financial access, and awareness campaigns could improve supply, durability, and acceptance, enable broader adoption of ICS and reduce reliance on traditional biomass in FOLUR project areas.

Table 15 Challenges of using and barriers to adoption of fuel-saving ICSs in FOLUR project areas

Category	Response	Frequency	Percentage
Problems Faced while using fuel-saving cookstove	Limited durability	99	34.14
	Technical complexity	56	19.31
	High maintenance cost	33	11.38
	Require more space	19	6.55
	Lack of local supply	122	42.07
Reasons for not using cookstoves	Limited awareness	1836	78.14
	Limited availability	1680	71.58
	High purchasing cost	1117	47.65
	Limited access to finance	1023	43.56
	Other	194	8.27

Source: Household survey (2024/25)

3.4.2. Biogas

Table 10 show that biogas remains highly underutilized in the FOLUR project areas, with only 0.76% of households reporting use, primarily for cooking (90%), lighting/heating (75%), and baking (55%). Most users have adopted biogas within the last 1–3 years, and NGOs are the main providers (70%), highlighting limited market access. These patterns indicate substantial barriers such as awareness, affordability, and availability but also suggest opportunities for targeted interventions to expand biogas as a versatile, clean energy option in forest-dependent Ethiopian communities, aligning with findings on the role of institutional support in promoting renewable household energy (Tesfay et al., 2024; Shallo & Sime, 2025).

Findings from FGDs and KIIs indicate that biogas adoption is low due to interlinked technical, financial, sociocultural, institutional, and environmental barriers. Technical challenges include high dung and water requirements, poor-quality construction, and lack of local maintenance, which often lead households to abandon systems. High installation costs, limited market availability, and absence of credit or cooperative models restrict affordability and access.

Table 10 Biogas use, purpose, duration, and source among respondents in FOLUR project areas

Category	Response	Frequency	Percentage
Biogas usage as an alternative energy source	No	2619	99.24
	Yes	20	0.76
Purpose of biogas usage	Cooking	18	90.00
	Lighting	15	75.00
	Baking	11	55.00
Length of time using biogas	In the last 1-3 years	7	35.00
	In the last 3-5 years	5	25.00
	Since above 5 years	4	20.00
	Since less than a year	4	20.00
Source of biogas	NGOs	14	70.00
	Government Agencies	4	20.00
	Purchased from market	2	10.00
	Locally Organized Cookstove Producers	1	5.00

Source: Household survey (2024/25)

Cultural norms and gender dynamics, such as preference for traditional fuels and male-dominated decision-making, further limit acceptance. Institutional gaps, including weak coordination among energy, agriculture, and livestock offices and reliance on donor-driven projects, undermine sustainability. Environmental constraints, like seasonal water shortages, limited livestock ownership, and forest canopy effects, reduce operational feasibility. Collectively, these factors highlight the need for targeted interventions technical training, financial support, local cooperative involvement, and culturally sensitive awareness programs to expand biogas use as a clean and versatile energy option in these communities.

Among the 122 respondents who provided feedback on biogas usage challenges, cost-related issues emerged as the most significant barrier, cited by 55.74% (Figure 4). This suggests that the initial investment or maintenance costs associated with biogas systems are prohibitively high for many households, even those aware of and interested in the technology.

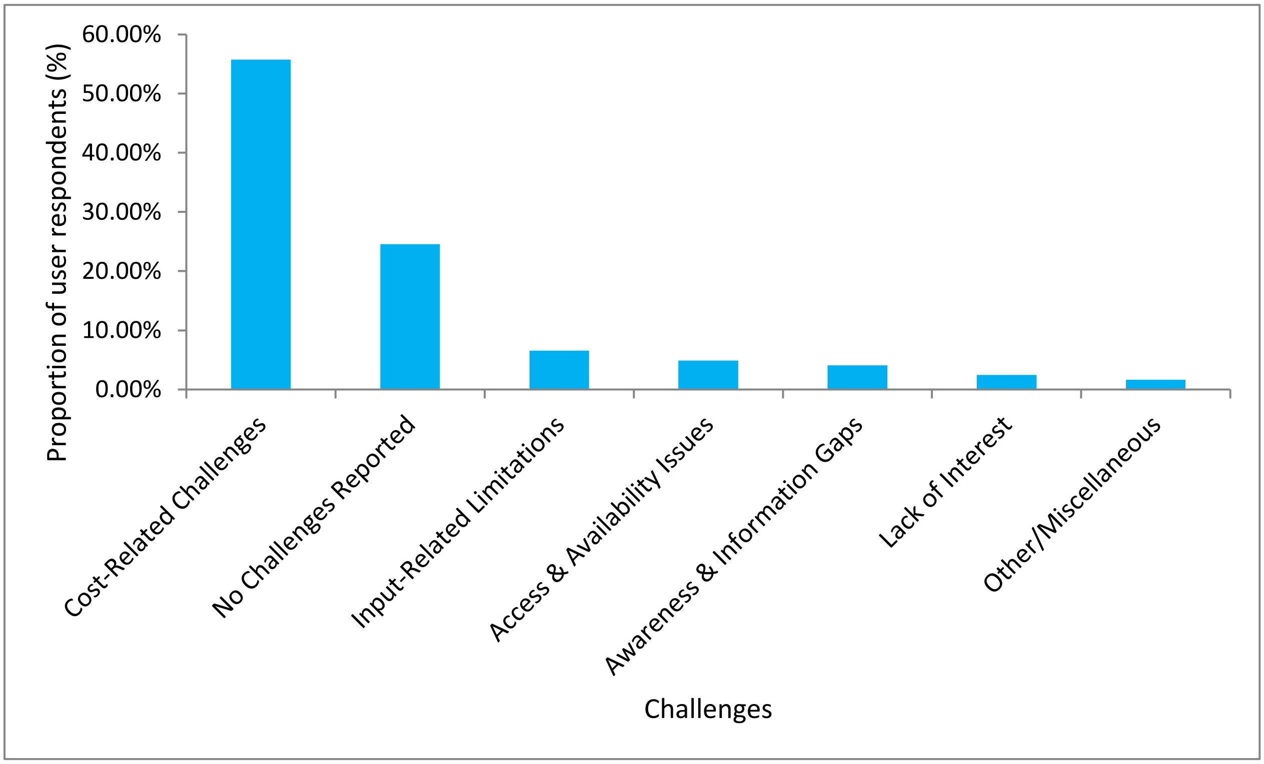


Figure 4 Challenges in accessing or using biogas among user respondents in FOLUR project areas

Source: Household survey (2024/25)

Interestingly, 24.59% reported no challenges, which indicates that once biogas systems are in place, a notable portion of users may find them reliable and beneficial. This reflects the potential for user satisfaction, especially when the systems are properly supported or subsidized. Other notable challenges include input-related limitations (e.g., insufficient organic material for biogas production) and limited availability and access to biogas technologies (6.56% and 4.92%, respectively). Smaller portions of respondents highlighted information gaps (4.10%) and lack of interest (2.46%), pointing to the need for better awareness-raising and demand generation strategies.

Overall, these findings emphasize the importance of financial support mechanisms, technical training, and market access improvements for scaling biogas adoption. For the

FOLUR project, addressing cost and accessibility barriers will be key to unlocking biogas as a viable clean energy solution across targeted intervention areas.

3.4.3. Solar Energy

In forest-dependent communities of Ethiopia, solar technology is increasingly used, with nearly 40% of households in the FOLUR project areas reporting utilization, primarily for lighting and device charging (Table 11). This reflects a gradual transition toward modern energy sources in regions historically reliant on biomass, although low choice for cooking and baking indicates persistent dependence on firewood and charcoal (Amare et al., 2015; Shallo & Sime, 2025). The predominance of market-based acquisition (95%) highlights the central role of private-sector distribution, with limited NGO or government involvement, which is consistent with findings from other rural Ethiopian studies emphasizing the importance of market availability for renewable energy uptake (Tesfay et al., 2024; Mekonnen et al., 2025). Long-term usage patterns, with over a third of households using solar for more than five years, indicate sustained engagement but also suggest barriers for new users, likely related to cost, access, and technical knowledge.

FGDs and KIIs indicate that solar energy adoption in forest-dependent communities is limited by accessibility, maintenance, and supply-chain challenges. Small solar lamps are common, but larger household or institutional systems are scarce and often fail due to poor maintenance, harsh environmental conditions, and lack of technical support. Remote locations, dense forest canopy, and high transportation costs further restrict access. Informal markets dominate, with minimal cooperative involvement. Participants suggested that training and supporting local women and youth cooperatives could improve availability, reliability, and community trust in solar technologies.

These patterns align with broader literature showing that solar choice in rural Ethiopia is concentrated in low-power applications and constrained by affordability, infrastructure, and socio-economic factors, underscoring the need for interventions that expand both access and functional uses of solar energy to enhance livelihoods and reduce biomass dependency (Beyene & Koch, 2013; Manaye et al., 2022).

Table 11 Solar technology use, purpose, duration, and source among respondents in FOLUR project areas

Indicator	Response	Frequency	Percentage
Usage of solar technology	No	1590	60.25
	Yes	1049	39.75
Purpose solar technology usage	Lighting/Heating	1034	98.57

	Charging	440	41.95
	Cooking	17	1.62
	Baking	14	1.34
	Other	2	0.19
Length of solar technology usage	Since above 5 years	404	38.53
	In the last 1-3 years	363	34.64
	In the last 3-5 years	216	20.61
	Since less than a year	66	6.29
From where do you get solar technology?	Purchased from market	997	95.04
	NGOs	44	4.20
	Government agencies	20	1.91
	Other sources	7	0.67
	Locally organized cookstove producers	1	0.10

Source: Household survey (2024/25)

The challenges faced by solar technology users are predominantly linked to durability and maintenance costs (
Table 12). A significant proportion of users, 82.06%, report that solar systems are less durable than expected, indicating a need for more reliable and longer-lasting solar technologies. Additionally, 42.69% find the maintenance costs associated with solar systems to be burdensome, which could discourage long-term use. Other challenges include the technical complexity of using solar technology (26.14%) and the requirement for more space (2.00%).

On the other hand, the reasons for not using solar technology highlight significant barriers, with 39.79% of respondents citing the high purchasing cost as a major deterrent. Other substantial reasons include limited awareness of solar technology (36.49%), limited availability (33.42%), and limited access to finance (30.01%). These findings underscore the need for financial assistance, awareness campaigns, and improved availability to encourage broader adoption of solar technologies in the region.

Table 12 Challenges in using and reasons for not using solar technology in FOLUR project areas

Challenge category	Types of challenges	Frequency	Percentage
Challenges while using Solar	Less durable	860	82.06
	High maintenance cost	448	42.69
	Technical complexity	274	26.14

	Require more space	21	2.00
	Other	86	8.21
Reasons for not using Solar	High purchasing cost	1050	39.79
	Limited awareness	963	36.49
	Limited availability	882	33.42
	Limited access to finance	792	30.01
	Other	178	6.74

Source: Household survey (2024/25)

These results suggest that interventions in the FOLUR project areas should prioritize affordable and durable solar products, and providing both financial support and information to encourage more households to adopt solar energy solutions.

The majority of solar technology users (60.47%) reported no challenges with the technology, which suggests that, for many users, the systems are working as expected (Table). However, a subset of users experienced issues, with quality and battery problems each affecting 10.47% of users. These issues could be related to the performance of solar systems or specific components like batteries, indicating that product quality and battery longevity could be areas for improvement.

Other challenges include cost-related difficulties (6.98%), which could relate to the affordability of replacement parts or additional systems. Maintenance and technical problems (3.49%) and weather-related factors (4.65%) may also contribute to the limited effectiveness of the technology in some regions. A small percentage (1.16%) noted the use of alternative energy sources, indicating that even among users; some might rely on a combination of energy sources to meet their needs. This highlights areas where solar technology providers and implementing organizations can focus their efforts, including improving product quality, ensuring robust batteries, and addressing maintenance challenges.

Table 19 Challenges reported by solar technology users

Challenge category	Frequency	Percentage
No challenges reported	52	60.47
Cost-related challenges	6	6.98
Quality issues	9	10.47
Battery issues	9	10.47
Maintenance & technical issues	3	3.49
Weather & environmental factors	4	4.65

Challenge category	Frequency	Percentage
Alternative energy source used	1	1.16
Total	86	100

Source: Household survey (2024/25)

The FGDs and KIIs also reveal that solar energy adoption in forest-dependent communities is constrained by multiple interrelated factors. Frequent equipment failures, low-quality products, lack of spare parts, and untrained technicians undermine durability and user confidence. High costs, limited access to credit, and weak supply chains restrict affordability, while low awareness, mistrust, and gendered decision-making reduce uptake. Environmental challenges, including dense forests, humidity, and remote locations, further limit system performance and maintenance. Institutional gaps, such as poor coordination and unsustainable donor-driven projects, exacerbate these barriers, highlighting the need for integrated technical, financial, and awareness interventions.

3.4.4. Electricity

The data reveals that the majority of respondents (81.09%) do not use grid electric power as an alternative source, indicating limited access to the grid in many areas (Table 13). Among the 499 users of grid electricity, the primary use is for lighting or heating (98.40%), followed by charging or powering devices (67.43%). Cooking and baking were less commonly used, with only 2.81% and 1% of users citing them as purposes, respectively. In terms of the length of usage, 44.48% of users have been using grid electric power for more than 5 years, suggesting some level of long-term adoption. However, a substantial portion, 34.89%, started using it within the past 1-3 years, and a smaller portion, 6.02%, began using it less than a year ago. These trends indicate ongoing access and a gradually expanding access to electricity in certain regions.

Table 13 Access and usage of grid electric power

Indicators	Response option	Frequency	Percentage
Usage of grid electric power as an alternative source	No	2140	81.09
	Yes	499	18.91
Purpose of grid electric power usage	Lighting or heating	491	98.40
	Charging or powering	336	67.43
	Other	17	3.41
	Cooking	14	2.81
	Baking	5	1.00
Length of time for grid electric power usage	Above 5 years ago	222	44.48
	In the last 1-3 years	174	34.89
	In the last 3-5 years	73	14.65

	Since less than a year	30	6.02

Source: Household survey (2024/25)

In forest-dependent communities of Ethiopia, the choice of alternative energy technologies is constrained by several interrelated challenges (Table 14). Limited awareness is the most frequently cited barrier, affecting 75% of households, indicating that knowledge gaps about the benefits, use, and maintenance of these technologies remain critical. High costs were reported by nearly 60% of respondents, underscoring affordability as a persistent obstacle in resource-constrained settings. Additionally, over half of households reported limited availability of technologies and infrastructure, while almost 48% highlighted restricted access to credit, reflecting structural and financial barriers that impede uptake. FGDs and KIIs revealed that adoption of alternative household energy technologies in Ethiopia's forest-dependent communities is limited by low awareness, high costs, poor availability, and lack of credit access. Many households are unaware of the benefits and maintenance of clean technologies, while high upfront costs and weak supply chains make adoption difficult. Limited access to finance further restricts uptake. Participants emphasized that expanding awareness, supporting local production, and improving financial access are critical to accelerating clean energy adoption under the FOLUR project. These findings are consistent with prior studies in rural Ethiopia, which emphasize that effective energy transition interventions require integrated strategies combining awareness campaigns, financial support mechanisms, and improved distribution networks to enhance access and use of sustainable household energy technologies (Amare et al., 2015; Tesfay et al., 2024; Shallo & Sime, 2025).

Table 14 Overall challenges affecting adoption of alternative household energy technologies

Challenge	Frequency	Percentage
Limited awareness	1,991	75.45
High cost	1,565	59.30
Limited availability	1,407	53.32
Limited access to credit	1,258	47.67
Other	334	12.66

Source: Household survey (2024/25)

Table 22 presents the distribution of alternative energy sources across the FOLUR intervention regions. The use of ICS varied considerably among regions. Oromia recorded the highest adoption at 23.7%, indicating substantial uptake. In contrast, ICS use in Sidama and South Ethiopia was minimal, reflecting very low penetration, while

South West Ethiopia showed modest adoption at 4.6%. Overall, 10.9% of households across the four regions reported using ICS.

Adoption of biogas was negligible across all regions. Oromia had the highest uptake at 1.4%, while Sidama and South Ethiopia recorded minimal adoption, and South West Ethiopia reported virtually no use. Overall, only 0.7% of households adopted biogas.
Solar technology showed substantial regional variation. Adoption was highest in Oromia (48.1%) and South West Ethiopia (57.6%), indicating widespread utilization. South Ethiopia had moderate adoption at 22.4%, whereas Sidama recorded minimal uptake. Overall, 39.7% of households across the four regions reported using solar energy.

Overall, the data indicate that solar technology and improved cookstoves are the most commonly adopted alternative energy sources, while biogas use remains negligible. Adoption patterns differ significantly by region, highlighting disparities in access to or preference for alternative energy solutions.

Table 15 Alternative Energy typology distribution by FOLUR intervention regional states

Energy Source	Oromia		Sidama		South Ethiopia		South West Ethiopia		Total	
	n	%	n	%	n	%	n	%	n	%
ICSs	240	23.7	2	0.5	9	2.2	37	4.6	288	10.9
Biogas	14	1.4	2	0.5	2	0.5	1	0.1	19	0.7
Solar	486	48.1	6	1.5	92	22.4	464		1048	39.74

Source: Household survey (2024/25)


Sample Tikikil stove picture


Sample Mirt stove picture

Figure 5 Sample pictures from distributed cookstoves in target areas

3. 5. Factors affecting choice of different alternative energy technologies in FOLUR Ethiopia project areas

Improved cookstove choice

Sex of household: Sex of the respondent is a highly significant determinant of improved cookstove adoption (Table 16). Male respondents are substantially more likely to choose improved cookstoves compared to female respondents. These finding underscores gender disparities in energy decision-making within rural Ethiopian households. Men often have greater access to financial resources, credit, and information about modern energy technologies through community meetings and local extension programs. In contrast, women though the primary users of cooking energy frequently have limited decision-making power and financial autonomy. Consequently, male-headed households or those where men make energy-related decisions are more likely to invest in improved cookstoves that enhance efficiency, reduce smoke emissions, and save time. This outcome also indicates the need for gender-inclusive energy awareness programs that empower women to make or influence decisions about adopting cleaner household technologies.

Table 16 Factors affecting choice of different alternative energy technologies

Explanatory Variables	Dependent variables: Alternative energy technologies choice					
	Improved Cookstove		Biogas		Solar	
	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Sex of household	0.987***	0.273	-0.014	0.338	-1.275***	0.158
Age	0.039***	0.013	0.014	0.015	0.004	0.006
Marital status	4.469	100.151	4.096	175.601	0.042	0.338
Education status	1.754***	0.520	1.130*	0.655	0.038	0.499
Family size	0.051	0.086	0.068	0.119	0.112***	0.043

Explanatory Variables	Dependent variables: Alternative energy technologies choice					
	Improved Cookstove		Biogas		Solar	
	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Number of female household members	-0.283*	0.156	-0.347*	0.198	-0.046	0.059
Quantity of drywood consumed	-0.039	0.140	-0.603	0.406	-0.334***	0.090
Quantity of charcoal consumed	0.127**	0.053	0.354***	0.110	-0.254*	0.133
Quantity of kerosene	-0.159*	0.09b 6	-0.684**	0.268	-0.001	0.001
Land owned	-0.988*	0.535	-1.890***	0.586	0.741	0.720
Beehive owned	0.825***	0.289	-0.457	0.570	0.421**	0.170
Separate kitchen owned	0.374	0.273	0.719*	0.406	0.686***	0.146
Distance from firewood source	0.193	0.264	-0.144	0.323	1.086***	0.126
_cons	-7.544	100.155	-3.638	175.604	-2.703***	0.844

*Note: ***, ** and * represents statistical significance level at 1%, 5% and 10%, respectively.*

Source: Household survey data analysis results (2024/25)

Age of Household head: Age has a positive and significant relationship with improved cookstove adoption. Older household heads are more likely to use improved cookstoves than younger ones. This may be attributed to the accumulated experience of older individuals, who better understand the long-term health and economic benefits of modern stoves, such as reduced respiratory diseases from indoor smoke and decreased time spent collecting firewood. Older respondents may also have greater social stability and more consistent income sources, enabling them to invest in alternative energy technologies. Conversely, younger households may prioritize immediate financial needs over energy efficiency investments, reflecting differing time horizons and perceptions of benefits.

Education level: Education plays a crucial role in influencing the likelihood of adopting improved cookstoves. More educated *household* heads are significantly more inclined to adopt such technologies. Education enhances awareness about the adverse health effects of traditional biomass fuels and the environmental consequences of deforestation. Educated individuals are also better positioned to access information about energy efficiency programs and government or NGO interventions promoting improved stoves. In the context of the FOLUR project areas, where deforestation threatens forest ecosystems, this finding highlights the importance of integrating educational campaigns with energy transition programs to increase adoption among less educated households.

Number of female members: The number of female household members is negatively associated with improved cookstove adoption. This result may seem counterintuitive, but it reflects the socio-cultural and economic realities of forest-dependent communities. Households with more women often rely heavily on freely collected biomass fuels, such as firewood and agricultural residues, which reduces the perceived need for fuel-efficient stoves. Moreover, such households may face resource constraints that prevent them from purchasing improved *stoves*. Despite women being the most affected by smoke exposure and firewood *scarcity*, their limited economic power can restrict adoption decisions. Targeted interventions aimed at empowering women economically and providing micro-financing options could enhance their capacity to adopt fuel-saving technologies.

Charcoal consumption: Charcoal consumption shows a positive and significant relationship with the adoption of improved cookstoves. Households that already rely on purchased fuels such as charcoal are more motivated to invest in improved cookstoves to reduce fuel costs. Improved *cookstoves* enable more efficient combustion, thus lowering charcoal expenditure. This suggests that fuel price sensitivity is an important driver of technological adoption. As charcoal becomes increasingly expensive due to supply constraints and forest depletion, households are likely to seek more efficient technologies to maintain affordability.

Quantity of kerosene used: *The* amount of kerosene consumed negatively influences the choice of improved cookstoves. Households that rely on kerosene for lighting or cooking perceive it as a relatively modern and convenient energy source compared to solid biomass. Consequently, these households have less incentive to invest in improved cookstoves. This substitution effect indicates that as households transition to kerosene or other modern fuels, their likelihood of adopting intermediate technologies such as improved stoves declines. Policy measures promoting multi-fuel efficiency or hybrid systems could help bridge this transition gap.

Land ownership: Land ownership is negatively associated with the adoption of improved cookstoves. Households owning larger tracts of land are less likely to adopt these technologies because they often have easier access to firewood from their land. The availability of free or low-cost fuel reduces the perceived economic benefit of improved stoves. In forest-dependent areas, landowners may continue traditional energy practices without feeling the pressure of fuel scarcity. This underscores the importance of designing incentives that emphasize the environmental and health advantages of improved stoves, even for households with abundant land.

Beehive ownership: Beehive ownership has a positive and significant effect on improved cookstove (ICS) adoption. Households engaged in beekeeping are typically more aware of forest conservation needs, as their livelihoods depend on healthy and productive local ecosystems. In addition, beekeeping can generate additional income through honey and hive products, increasing the household's purchasing power. This higher income enables households to afford improved cookstoves, which often require an upfront investment, while also supporting sustained use and maintenance. Therefore, the observed association between beehive ownership and ICS adoption likely reflects both environmental awareness and the financial capacity to invest in clean energy technologies.

Biogas technology choice

Education level: Education level positively influences the likelihood of adopting biogas technology. Educated individuals are more likely to understand the long-term economic and health benefits of biogas, including reduced dependence on firewood and the productive use of animal waste. Education also increases exposure to development programs and technical training necessary for biogas installation and maintenance. Therefore, enhancing education and technical awareness within rural communities could substantially increase biogas adoption rates.

Number of female members: A higher number of female members in a household negatively affects biogas adoption. Households with many women may rely on traditional cooking practices using freely collected biomass, limiting the perceived need for biogas systems. Additionally, these households might lack the financial resources or technical capacity to invest in biogas infrastructure. Cultural norms that restrict women's decision-making authority in household investments may also contribute to this outcome. Interventions that empower women through income-generating activities or group financing models could promote greater biogas adoption.

Charcoal consumption: Charcoal consumption significantly and positively affects biogas adoption. Households that already spend money on charcoal are motivated to seek alternative, more sustainable energy sources to reduce long-term expenditure. Biogas provides a renewable and cost-saving solution, especially for households with livestock and organic waste availability. This finding indicates that the commercialization of biomass fuels can indirectly encourage the shift toward renewable technologies like biogas.

Quantity of kerosene used: The negative and significant relationship between kerosene use and biogas adoption suggests that households already using kerosene perceive less benefit from adopting biogas. Kerosene users typically associate it with convenience and modernity, reducing their willingness to invest in biogas systems that require maintenance and infrastructure. This indicates that biogas promotion strategies must emphasize its multiple co-benefits such as improved sanitation, organic fertilizer production, and reduced deforestation to compete effectively with other modern fuels.

Land ownership: Land ownership shows a strong negative relationship with biogas adoption. Land-rich households often have ample biomass resources and grazing land for fuel collection, making them less motivated to invest in biogas systems. Furthermore, wealthier landowners may prioritize agricultural expansion over renewable energy investment. Policymakers should therefore target smallholders and livestock-keeping households with tailored biogas promotion efforts, highlighting both energy and agricultural benefits.

Separate kitchen ownership: Owning a separate kitchen positively influences the likelihood of adopting biogas technology. A separate cooking space not only reflects higher living standards but also provides suitable conditions for biogas infrastructure installation. Such households are more organized and better able to accommodate modern energy systems, suggesting that biogas adoption is closely linked to overall household development.

Solar technology choice

Sex of household: Sex of the respondent has a strong negative influence on solar technology adoption, indicating that female respondents are significantly less likely to use solar technologies than male respondents. This gender gap may arise from differences in access to capital, information, and training. Women in rural Ethiopia often have limited engagement with technology markets and less exposure to energy programs. Addressing this disparity requires gender-sensitive energy interventions, including women-focused microcredit schemes and training programs to enhance solar technology adoption.

Total family size: Larger household size significantly increases the likelihood of solar technology adoption. Bigger families have higher energy needs, particularly for lighting and phone charging, which makes solar systems more attractive. Additionally, larger households may pool resources more effectively to invest in solar panels. This suggests that promoting community-based or group purchasing models for solar systems could be particularly effective in the FOLUR project areas.

Drywood consumption: Higher levels of drywood consumption are negatively associated with solar technology adoption. Households that rely heavily on firewood tend to continue using traditional energy sources, often because of habit, cultural preferences, or lack of awareness of solar alternatives. The continued availability of free biomass energy further reduces the perceived need to invest in solar technology. Efforts to reduce firewood dependence should therefore be coupled with education on the long-term economic benefits of solar energy.

Charcoal consumption: Charcoal consumption also negatively affects solar adoption. This suggests that charcoal users, who are accustomed to traditional fuel-based systems, may prioritize meeting cooking energy needs rather than investing in solar lighting technologies. The cultural preference for cooking with solid fuels and the limited affordability of solar systems contribute to this outcome.

Beehive ownership*:* Beehive ownership significantly and positively influences solar technology adoption. Households engaged in beekeeping are often environmentally conscious and rely on healthy forest ecosystems for their livelihoods, which makes them more inclined to adopt clean energy systems that reduce deforestation. In addition, beekeeping can generate additional income through the sale of honey, increasing the household's purchasing power. Solar lighting can also support night-time honey processing, enhance productivity and provide a practical incentive for adoption. Thus, the observed association between beehive ownership and solar technology adoption likely reflects a combination of environmental awareness, productivity benefits, and financial capacity.

Separate kitchen ownership: Owning a separate kitchen is strongly and positively associated with solar technology adoption. This reflects higher socio-economic status and household organization. Wealthier households with better infrastructure are more likely to invest in modern energy systems, including solar lighting and appliances. This finding highlights the role of economic capability in determining access to clean energy.

Distance from firewood source: Distance to firewood sources is one of the most influential factors in solar technology adoption. Households located farther from forest areas experience higher time and labor costs in collecting firewood. As a result, they are more likely to seek alternative energy sources, with solar systems providing a reliable and sustainable option. This finding demonstrates how resource scarcity can drive transitions toward renewable energy technologies.

Correlation among alternative energy technologies

There is a significant positive correlation between improved cookstove and biogas adoption ($\rho_{21} = 0.525$, $p < 0.01$). This indicates that households adopting one fuel-saving technology are more likely to adopt another. The positive relationship between biogas and solar technologies ($\rho_{32} = 0.189$, $p < 0.10$) further suggests complementarity among clean energy options. These relationships highlight an integrated approach to energy transition, where awareness, affordability, and technology availability jointly influence household decisions. Programs promoting a mix of energy solutions could therefore accelerate the shift toward sustainable energy systems in forest-dependent communities of the FOLUR project areas.

3.6. Training on different alternative household energy technologies

The data on access and participation in ICS training reveals significant gender dynamics in the household decision-making process regarding the adoption and use of improved cookstoves (ICS). According to the results, 72.41% of respondents reported that the wife receives training on ICS use, with 16.90% of husbands also undergoing training and 10.69% of households making joint decisions on who receives the training (

). This suggests that women are primarily targeted for training, likely because they are the main users of cookstoves in many households. These figures are consistent with broader gender roles where women are central to household energy management.

When it comes to procurement, 64.83% of the decisions regarding the purchase of ICS are made by the wife, with 18.97% of decisions made by the husband, and 16.20% of households making joint decisions. This underscores the active role of women in managing household energy resources, particularly in acquiring technologies that improve efficiency and reduce environmental impact. In terms of maintenance decisions, 42.76% of households report that joint decision-making occurs regarding the maintenance of ICS, while 40.69% of the time the wife is the primary decision-maker. These findings point to the importance of shared responsibility but still highlight the significant role of women in managing the maintenance of household Technologies.

The high participation of women in the training and decision-making processes for ICS indicates that such interventions are successfully targeting the right demographic and could lead to increased adoption of efficient, low-carbon technologies. Furthermore, ensuring that men are also involved in decision-making about energy use and maintenance, as seen in the joint decision-making percentages, is crucial for the gender-sensitive approaches promoted by the FOLUR project. By fostering both capacity building for women and encouraging inclusive decision-making between spouses, the FOLUR project aligns with its goals of improving household energy efficiency and reducing environmental degradation, while also addressing gender equality and social inclusion. The data suggests that such interventions, if scaled, could lead to broader acceptance and long-term use of sustainable energy solutions within communities.

Table 17 Household roles in training, procurement, and maintenance of ICSs

Indicator	Response option	Frequency	Percentage
Who is receiving training on the use of improved cookstoves?	Wife	210	72.41
	Husband	49	16.90
	Joint decision	31	10.69
Who procures improved cookstoves?	Wife	188	64.83
	Husband	55	18.97
	Joint decision	47	16.20
Who makes decisions on the maintenance of improved cookstoves?	Joint decision	124	42.76
	Wife	118	40.69
	Husband	48	16.55

Source: Household survey (2024/25)

FGDs confirmed that women are typically more engaged and proactive in learning about improved cookstoves, valuing the associated benefits such as reduced smoke exposure, time savings, and improved cooking efficiency. Several participants noted that women-led discussions and demonstrations increased confidence and peer-to-peer learning within communities. Maintenance decisions, however, tend to involve both men and women, with many households reporting shared responsibilities a sign of growing cooperation in managing household energy resources. The KIIs show these findings, emphasizing that empowering women through training and access to resources significantly enhances the adoption and sustained use of fuel-efficient stoves. Local development agents and energy officers highlighted that when women are directly targeted in awareness and capacity-building programs, technology uptake and continued use improve markedly.

The data on access and participation in biogas training highlights important gender dynamics in decision-making related to the adoption and management of biogas systems in households (

Table 18). According to the results, 55% of the respondents reported that the husband receives the biogas training, while 35% of wives are trained, and 10% of households make joint decisions regarding training. This indicates that although men are primarily receiving the training, there is still a significant proportion of women involved, which could enhance the adoption of biogas systems across households.

Table 18 Household roles in training, procurement, and maintenance of Biogas

Indicator	Response	Frequency	Percentage
Who receives training on the use of biogas in your household?	Husband	11	55.00
	Wife	7	35.00
	Joint decision	2	10.00
Who makes decisions on installation or procurement of biogas?	Husband	11	55.00
	Joint decision	6	30.00
	Wife	3	15.00
Who makes decisions on maintenance of biogas?	Husband	11	55.00
	Wife	5	25.00
	Joint decision	4	20.00

Source: Household survey (2024/25)

In terms of decision-making on biogas installation or procurement, 55% of the households' report that husbands make the final decision, while 30% of decisions are made jointly, and 15% of decisions are made by the wife. This suggests that men tend to dominate the decision-making process in the procurement and installation of biogas systems, but joint decision-making also plays a role, reflecting a degree of collaboration between spouses. When it comes to maintenance decisions, 55% of the households' report that the husband is responsible, 25% say the wife makes decisions, and 20% report that decisions are made jointly. This indicates that, similar to procurement and training, men are primarily responsible for the maintenance of biogas systems in these households, but joint decision-making and involvement from women are also observed.

These findings are important for the FOLUR project, which aims to promote sustainable energy solutions, such as biogas, in rural communities while enhancing gender equality and social inclusion. The dominance of male decision-making in biogas-related activities may suggest that interventions focused on capacity-building for both men and women are essential for broader adoption and effective utilization of biogas systems.

The project could strengthen its approach by emphasizing gender-sensitive training and ensuring that both women and men are equally involved in the decision-making process regarding biogas installation, maintenance, and usage. This could help to increase the adoption rates of biogas technologies and improve sustainability by ensuring that both household members are engaged and equipped to maintain the systems. Moreover, focusing on joint decision-making could enhance cohesion and cooperation in households, which is crucial for the long-term success of biogas and other sustainable energy technologies promoted by the FOLUR project.

The data on access and participation in solar technology training demonstrates notable gender dynamics in decision-making processes within households (Table 19). Regarding solar training, a significant proportion of the husbands (54.15%) receive the training, while 37.10% of households engage in joint decision-making and only 8.75% of wives are trained. This suggests that men are more likely to participate in solar technology training, though there is still considerable involvement from women, especially when decisions are made jointly.

In terms of decision-making on the procurement or installation of solar technology, 46.97% of decisions are made by the husband, and 46.53% of the decisions are made jointly between the couple. Only 6.59% of decisions are made by the wife alone. This indicates that men continue to play a dominant role in making procurement and installation decisions, although joint decision-making is quite prevalent, reflecting a shared responsibility in the process. For the maintenance of solar technology, 50.45% of households report that decisions are made jointly between the husband and wife, while 44.03% say the husband is primarily responsible, and 5.53% report that the wife handles maintenance decisions. The significant proportion of joint decision-making in maintenance indicates collaborative efforts in sustaining the technology.

These findings are important for the FOLUR (Food and Land Use Reform) project, which seeks to support sustainable energy solutions, such as solar technology, in rural areas while fostering gender equality. Given the trends, the project could benefit from promoting gender-equitable training and decision-making processes. It is crucial to encourage more participation of women in training and decision-making roles, particularly in households where men tend to dominate these activities. By integrating gender-sensitive approaches, the FOLUR project can further enhance the adoption and sustainability of solar technologies, ensuring both men and women are fully equipped and involved in the use, maintenance, and decision-making surrounding solar energy solutions. This balanced involvement could lead to more effective and long-term integration of solar technologies within households.

Table 19 Household roles in training, procurement, and maintenance of Solar Technology

Indicator	Response	Frequency	Percentage
Who receives training on the use of solar technology in your household?	Husband	568	54.15
	Joint decision	389	37.10
	Wife	92	8.75
Who makes decisions on procurement or installation of solar technology?	Husband	492	46.97
	Joint decision	488	46.53
	Wife	69	6.59
Who makes decisions on maintenance of solar technology?	Joint decision	529	50.45
	Husband	462	44.03
	Wife	58	5.53

Source: Household survey (2024/25)

Participants in FGDs emphasized that men often take the lead in financial and technical decisions due to traditional social norms, while women’s involvement tends to focus on day-to-day management and maintenance. The KIIs with community representatives corroborated this, noting that households achieve better utilization and sustainability of solar systems when women are actively engaged in both training and joint decision-making. Qualitative discussions also highlighted that training programs are often insufficiently inclusive, and women’s limited participation can hinder long-term adoption and proper use.

The results indicate that training and awareness regarding improved household energy technologies in the FOLUR project areas remain markedly low, with 87.7% of respondents reporting no prior training. Among those who received training, only half perceived it as very important, and a substantial portion rated it as insufficient or poorly timely, suggesting gaps in both content quality and delivery (Table 20). The main reasons for not participating included lack of outreach (71.1%), distance to training centers (16.5%), and absence during scheduled sessions (15.1%), highlighting logistical and communication barriers. Findings from FGDs and KIIs with community representatives emphasized that insufficient training and awareness limit effective use and choice of alternative energy technologies such as ICS, biogas, and solar systems. Furthermore, FGDs revealed that while households are generally willing to adopt these technologies, their ability to do so effectively depends on accessible, high-quality, and well-structured training, as well as ongoing technical support.

Table 20 Status of overall training on alternative household energy technologies

Indicator	Response options	Frequency	Percentage
Received training or awareness on the benefits, usage, procurement, and maintenance of either of improved household energy technologies	No	2315	87.72
	Yes	304	11.52
Rate the importance of the training or awareness on the benefits, usage, procurement, and maintenance of either of improved household energy technologies	Very important	152	50.00
	Fairly important	64	21.05
	Have little importance	35	11.53
	Somehow important	31	10.20
	Not important or relevant at all	22	7.24
Rate the sufficiency of the training or awareness on the benefits, usage, procurement, and maintenance of either of improved household energy technologies	Limited sufficiency	75	24.68
	Fairly sufficient	67	22.04
	Very sufficient	65	21.38
	Somehow sufficient	62	20.39
	Insufficient at all	35	11.48
Rate the timeliness of the training or awareness on the benefits, usage, procurement, and maintenance of either of improved household energy technologies	Poorly timely	88	28.95
	Fairly timely	75	24.68
	Somehow timely	70	23.03
	Very timely	40	13.16
	Not timely at all	31	10.20
Reason why didn't receive training or awareness on the benefits, usage, procurement, and maintenance of either of improved household energy technologies	Agencies didn't approach or invite us to the training & awareness events	1876	71.09
	We live in a location very far from training and awareness creation centers	435	16.48
	I was not present during the training or awareness creation event	398	15.08
	Have no reason or idea	171	6.48
	I am not interested in improved household energy technologies	164	6.21
	I have physical disability to travel to training centers	99	3.75
Source of information access about the benefits, usage, procurement, and maintenance of either of improved household energy technologies	NGO projects	159	52.30
	Government extension	109	35.84
	Neighbors or friends	93	30.59
	Radio	68	22.37
	TV	30	9.87
	Other	9	2.95

Source: Household survey (2024/25)

These findings resonate with previous studies in rural Ethiopia and Sub-Saharan Africa, where limited training, poor timing, and inadequate accessibility have been shown to restrict household uptake of clean energy technologies, such as ICSs and solar systems (Asfaw et al., 2019; Kassa et al., 2020). Moreover, the reliance on NGOs (52.3%) and government extension services (35.8%) as primary information sources underscores the critical role of formal institutions in disseminating knowledge, though informal networks such as neighbors also contribute substantially, reflecting community-based knowledge diffusion (Tadele et al., 2021).

These understandings suggest that enhancing the reach, relevance, and timing of training programs is essential for boosting awareness and engagement with energy-efficient technologies in forest-dependent communities. Integrating gender-sensitive approaches is also crucial, given that energy decision-making and technology use often vary by gender, affecting choice patterns and household energy practices (Shallo & Sime, 2021).

Effective interventions could include mobile or decentralized training programs, partnerships with local NGOs and community leaders, and reinforcement of informal knowledge networks to ensure equitable access. In line with evidence from Ethiopia and similar contexts, comprehensive training combined with accessible, locally appropriate technologies can significantly improve household energy efficiency, reduce reliance on traditional biomass fuels, and support sustainable land-use practices promoted by initiatives such as FOLUR (Amare et al., 2017; Mekonnen et al., 2018).

3.7. Contribution of Alternative Energy Technologies for reduction of Deforestation Rate

3.7.1. Fuelwood Saving and Emission Reduction

Several studies in Ethiopia have quantified the impact of ICS, biogas, and solar cooking technologies on household fuelwood consumption and associated CO_2 emissions (Table 21). ICS technologies, such as the Mirt and Tikikil stoves in Tigray, have been shown to reduce household fuelwood use by 35% and 18%, respectively, compared to traditional three-stone stoves (Manaye et al., 2022). Similarly, Mirt stoves in the Kafa Biosphere Reserve reduce fuelwood use by approximately 1.28 tons per household annually, achieving CO_2 emission reductions at the community scale of nearly 11,800 tons from 11,156 stoves (Dresen et al., 2014). In the Central Highlands, efficiency improvements of up to 54% relative to traditional stoves also translate into substantial CO_2 reductions (Gebreegziabher et al., 2018).

Biogas systems offer even higher per-household fuelwood and emission savings. Studies in the Central Rift Valley and North Shoa show that households using biogas saved 1.13–1.86 tons of fuelwood annually, with CO_2 emission reductions ranging from 1.6 to 2.75 tons per plant (Kefalew et al., 2021; Lemma et al., 2025). Solar cooking technologies, although less widely adopted in Ethiopia, have been modeled to save approximately 1.5

tons of fuelwood per solar stove annually, indirectly reducing CO_2 emissions by avoiding biomass combustion (MoWE, 2019). These findings collectively demonstrate that adopting cleaner energy solutions can significantly reduce both household fuelwood demand and greenhouse gas emissions.

Studies in Ethiopia show that CS, biogas systems, and solar cooking technologies significantly reduce household fuelwood consumption and associated greenhouse gas emissions. ICS, such as Mirt and Tikikil stoves, reduce fuelwood use by 18–54%, translating into CO_2 emission reductions of 0.3–0.7 tons per household annually (Manaye et al., 2022; Dresen et al., 2014). Biogas systems offer higher savings, with households reducing 1.1–1.9 tons of fuelwood per year and cutting 1.6–2.75 tons of CO_2 emissions per plant (Kefalew et al., 2021; Lemma et al., 2025). Solar cooking, though less adopted, shows modeled potential to save ~1.5 tons of fuelwood per stove annually, indirectly reducing emissions (MoWE, 2019).

Table 21 Fuelwood Saving and Emission Reduction from ICS, Biogas and Solar Technologies in Ethiopia

Technology	Study Area / Context	Fuelwood Saving / Reduction	Emission Reduction (CO_2e)	Reference (Author, Year)
Improved Cookstove (Mirt, Tikikil)	Tigray Region	35% (Mirt) and 18% (Tikikil) reduction compared to traditional stove	0.70 t CO_2e/year (Mirt); 0.30 t CO_2e/year (Tikikil) per household	Manaye et al., 2022
Improved Cookstove (Mirt)	Kafa Biosphere Reserve	~1.28 tons fuelwood saved per household/year (~40% reduction)	~11,800 t CO_2 saved from 11,156 stoves (project level)	Dresen et al., 2014
Improved Cookstoves (various types)	Central Highlands Ethiopia	Up to 54% fuel saving compared to three-stone stove	Significant CO_2 reduction due to reduced biomass use	Gebreegziabher et al., 2018
Improved Cookstoves (various types)	Rural Ethiopia	20–41% biomass fuel reduction	Reduced CO and CO_2 emissions relative to traditional stove	Fekadu et al., 2024
Biogas Technology	Girar Jarso, North Shoa	~1.13 tons fuelwood saved per household/year	~1.6 t CO_2e reduced per household/year	Lemma et al., 2025
Biogas Technology	Central Rift Valley	~1.86 tons fuelwood saved per household/year	~2.75 t CO_2e reduced per plant/year	Kefalew et al., 2021
Solar Cooking (modeled scenario)	National Clean Cooking Roadmap	~1.5 tons fuelwood saved per solar stove/year (scenario estimate)	Indirect CO_2 reduction from avoided biomass combustion	MoWE, 2019

3.7.2. Contribution to Deforestation Reduction / Forest Conservation

In addition to reducing fuelwood use and emissions, cleaner energy technologies contribute to forest conservation (Table 29). ICS technologies reduce biomass extraction, lowering pressure on local forests. For instance, Mirt stoves in Kafa not only save fuelwood but also help conserve approximately 30 hectares of forest carbon equivalent (Dresen et al., 2014). In Tigray, adoption of Mirt and Tikikil stoves reduces household wood demand, decreasing pressure on natural forests and shrublands (Manaye et al., 2022). Rural Ethiopia studies indicate 20–41% reductions in biomass extraction with ICS use, supporting forest conservation (Fekadu et al., 2024).

Biogas systems contribute to deforestation reduction by substituting fuelwood. In the Central Rift Valley and North Shoa, biogas adopters significantly reduce annual wood harvesting, thus contributing to forest preservation (Kefalew et al., 2021; Lemma et al., 2025). Solar technologies, while currently limited in adoption, have been projected at the national level to substantially reduce biomass pressure on forests if scaled up (MoWE, 2019). Collectively, these interventions demonstrate that energy technology adoption can mitigate forest loss while supporting sustainable environmental management.

Clean energy technologies in Ethiopia also contribute to forest conservation. ICS adoption decreases biomass extraction by 20–41%, reducing pressure on forests and shrublands (Fekadu et al., 2024; Manaye et al., 2022). Biogas systems directly substitute fuelwood, preventing annual forest wood harvesting of 1.1–1.9 tons per household (Kefalew et al., 2021; Lemma et al., 2025). Solar cooking, at a national scale, has the potential to significantly reduce forest pressure through widespread biomass displacement (MoWE, 2019). Collectively, these interventions support both sustainable household energy use and forest preservation.

Table 29 Contribution of ICS, Biogas and Solar Technologies to Deforestation Reduction / Forest Conservation in Ethiopia

Technology	Study Area / Context	Contribution to Forest Saving / Deforestation Reduction	Reference (Author, Year)
Improved Cookstove (Mirt)	Kafa Biosphere Reserve	Reduced forest degradation; CO_2 savings equivalent to carbon stored in ~30 ha of forest	Dresen et al., 2014
Improved Cookstoves	Tigray Region	Reduced household fuelwood demand decreases pressure on natural forests and shrublands	Manaye et al., 2022
Improved Cookstoves	Rural Ethiopia	20–41% reduction in biomass extraction contributes to lower forest resource depletion	Fekadu et al., 2024
Biogas Technology	Central Rift Valley	Significant substitution of fuelwood reduces dependence on forest resources	Kefalew et al., 2021

Biogas Technology	North Shoa	Reduced annual wood harvesting per household (~1.13 tons) contributes to forest conservation	Lemma et al., 2025
Solar Cooking / Solar Energy	National Level (Planning Scenario)	Large-scale adoption projected to substantially reduce biomass pressure on forests	

3.8. Projection of future demand for fuel-saving technologies in the four FOLUR project regions

The projected future demand for household energy sources, as shown in the graph, highlights clear trends in the usage patterns over 1, 5, and 10 years (Figure 6). Drywood remains the dominant energy source throughout the projection period. Starting from approximately 1 million total units of annual usage in Year 1, demand for drywood is projected to increase steadily to around 1.1 million units by Year 5 and further to about 1.3 million units by Year 10. This indicates a strong continued reliance on drywood for cooking, baking, and heating purposes, reflecting slow shifts towards alternative cleaner technologies unless interventions are made.

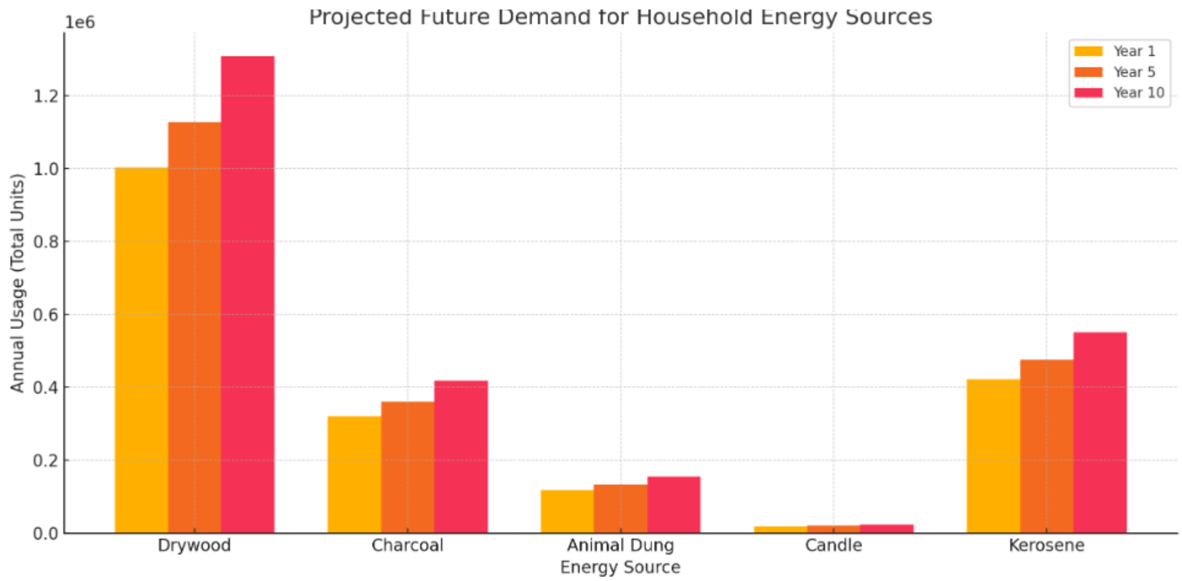


Figure 6 Projected future household energy sources

This finding is supported by the FGDs, where participants emphasized the importance of training and capacity-building to ensure the effective use of energy-efficient technologies such as ICSs, biogas, and solar systems. The FGD further stated the need for access to durable and high-quality technologies and financial support or credit to overcome affordability and reliability challenges.

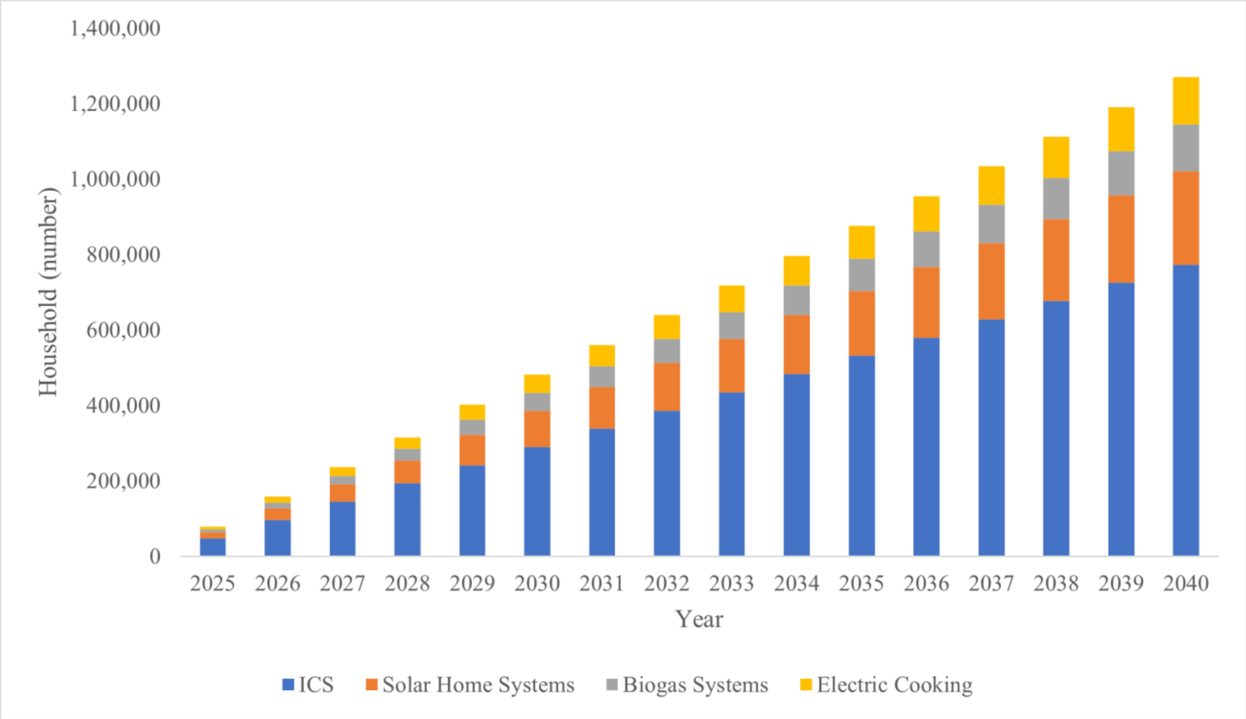
Charcoal use also shows an upward trend but at a more modest rate compared to drywood. From roughly 300,000 units in Year 1, it rises to around 350,000 units in Year 5 and to about 420,000 units by Year 10. This suggests that while charcoal remains a secondary energy source, its role in household energy supply is still significant, likely due to its relatively easier availability and cooking convenience.

Animal dung consumption exhibits moderate growth over the projection period. Initially low, the use of animal dung increases slightly but steadily, reaching a higher, though still relatively modest, level by Year 10. This growth may reflect continued reliance among lower-income or rural households, although it is much less significant compared to drywood and charcoal.

Candle usage remains very low throughout the projection period, with only a slight increase over time. This reflects candles' role as a minor source of lighting, often used as a backup rather than a primary energy source, and possibly declining relative importance with the expansion of electrification and other lighting options. Kerosene shows a steady increase in demand, growing from around 420,000 units in Year 1 to approximately 570,000 units by Year 10. This steady rise points to kerosene's continued relevance for lighting and some heating purposes, particularly in areas where grid electricity access remains limited or unreliable.

Overall, the projections suggest that without significant policy interventions and large-scale dissemination of fuel-saving and clean energy technologies, traditional biomass fuels like drywood and charcoal will continue to dominate the household energy mix, posing challenges for environmental sustainability and public health. Efforts to promote improved cookstoves, biogas, solar, and grid electricity alternatives will be critical to altering these trajectories and reducing dependency on traditional biomass sources.

Baseline data collected from sampled woredas within the FOLUR project landscapes indicate a relatively low initial level of adoption of fuel-saving and alternative energy technologies. These baseline figures provide the foundation for projecting future adoption trends and reflect current household energy use patterns in the sampled areas. Using this baseline, projections were developed to estimate potential adoption pathways over the period 2025–2040 under favorable enabling conditions, assuming a 20% annual growth rate in adoption (



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The projections are based on several key assumptions and enabling conditions: sustained government policies and incentives promoting clean energy technologies, availability of affordable financing mechanisms such as microfinance or pay-as-you-go schemes to reduce upfront costs, ongoing awareness campaigns and capacity-building initiatives to highlight the health, economic, and environmental benefits of alternative energy, reliable supply chains ensuring access to technologies and spare parts in rural and semi-urban areas, and the presence of complementary infrastructure and resources, including electricity for electric cooking, water and livestock for biogas systems, and technical support for installation and maintenance. These conditions collectively create an environment conducive to accelerating adoption and achieving the projected growth trajectories.

Improved Cookstoves (ICSs) emerge as the most widely adopted technology throughout the study period, with household adoption projected to increase from approximately 48,000 in 2025 to over 773,000 by 2040 under the 20% annual growth assumption. This growth reflects the affordability, simplicity, and cultural compatibility of ICSs with traditional cooking practices. ICSs represent the most scalable and immediately impactful intervention for reducing household biomass fuel consumption and alleviating pressure on forest resources, making them a central technology in FOLUR landscapes.

Solar Home Systems also demonstrate substantial growth, rising from about 15,000 households in 2025 to nearly 248,000 by 2040. Although adoption remains lower than ICS, the steady upward trend reflects expanding access to off-grid electricity solutions in rural and semi-urban areas, driven by declining technology costs, improved market availability, and growing household demand for electricity services. Solar energy adoption diversifies household energy sources and contributes to improved living standards in areas with limited grid access.

Biogas systems and electric cooking technologies show moderate but consistent growth, each increasing from approximately 7,700 households in 2025 to around 125,000 by 2040. Growth depends on enabling conditions such as livestock availability, water access, reliable electricity, and technical support. Biogas provides a cleaner alternative to fuelwood, reducing indoor air pollution and household dependence on biomass, while electric cooking complements other clean energy options and contributes to a diversified household energy portfolio, particularly in semi-urban and peri-urban areas.

Overall, the combined adoption of these alternative energy technologies has significant potential to reduce biomass fuel use, alleviate pressure on forest resources, and contribute to climate change mitigation across FOLUR landscapes. The assumed 20% annual growth rate reflects an optimistic but plausible scenario where financing, policy incentives, awareness creation, and technology accessibility align to accelerate adoption. Deviations from these conditions, such as delays in infrastructure development, insufficient financing, or limited community engagement, could slow adoption trajectories, highlighting the importance of integrated strategies and sustained investment. The findings underscore the critical need for policy support, effective financing mechanisms, capacity building, and robust market development to translate baseline adoption levels into long-term environmental, health, and socio-economic benefits in FOLUR landscapes.

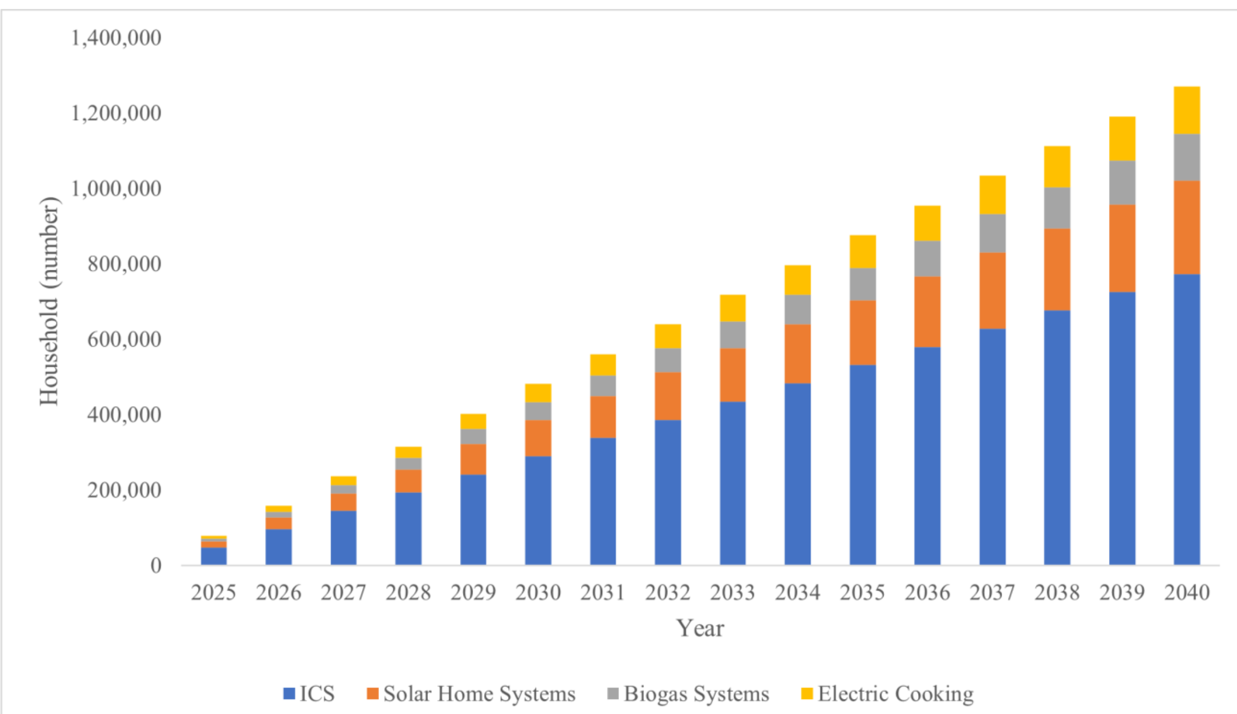

Figure 7 Projected adoption of fuel-saving technologies and other alternative energy sources over the next 15 years across all FOLUR project areas in Ethiopia.

This projection underscores the urgent need for supportive policies, financing schemes, and capacity-building initiatives to ensure equitable access, technology sustainability, and integration with environmental goals. It also signals that future modeling should incorporate population growth and market saturation to produce more conservative and realistic adoption estimates.

3.9. Future intervention for sustainable alternative household energy technologies

The findings from this section indicate a robust willingness among respondents (99.01%) to participate in the generation, utilization, or improvement of household energy technologies in the future (Table). This strong interest in transitioning towards sustainable and efficient energy practices aligns with the objectives of the FOLUR initiative. FOLUR aims to foster sustainable food systems and land use practices, with the integration of clean and efficient energy solutions playing a pivotal role in the functionality of agricultural systems, cooking practices, and land restoration efforts.

Table 30 Future participation in alternative energy technologies

Priorities	Response	Frequency	Percentage
Willing to participate in generation, utilization, or improvement of household energy technologies in the future	Yes	2613	99.01
	No	26	0.99
1st priority support need regarding improved household energy technologies	Training	1870	71.59
	Access to high quality and durable technologies	342	13.08
	Financial services (credit)	294	11.26
	Fair pricing of energy technologies	76	2.91
	Regular technical guidance (mentoring)	28	1.07
	Have no idea	3	0.11
2nd priority support need regarding improved household energy technologies	Access to high quality and durable technologies	1309	50.12
	Financial services (credit)	523	20.02
	Training	293	11.22
	Fair pricing of energy technologies	288	11.03
	Regular technical guidance (mentoring)	195	7.47
	Have no idea	5	0.19

Priorities	Response	Frequency	Percentage
3rd priority support need regarding improved household energy technologies	Financial services (credit)	821	31.43
	Fair pricing of energy technologies	605	23.18
	Access to high quality and durable technologies	508	19.44
	Training	390	14.92
	Regular technical guidance (mentoring)	277	10.60
	Have no idea	12	0.46

Source: Household survey (2024/25)

Training as a priority support need:

A significant portion (71.59%) of respondents identified training as their primary support need. This reflects the recognition of the importance of acquiring the knowledge and skills necessary for effectively utilizing improved household energy technologies. In the context of FOLUR, this highlights the need for capacity-building within rural communities, particularly among farmers, to ensure they are well-equipped to transition to and benefit from sustainable energy solutions. Training programs could focus on the proper use of energy-efficient technologies such as improved cookstoves, biogas, and solar power. This would help communities improve their energy efficiency, reduce dependence on traditional, polluting energy sources like firewood and charcoal, and enhance their sustainability.

FOLUR's objectives of promoting sustainable land management and improving the resilience of farming systems depend heavily on enhancing the livelihoods of smallholder farmers. Many of these farmers may currently rely on traditional energy sources that are inefficient and harmful to the environment. By focusing on education and training, FOLUR can equip these communities with the skills to embrace renewable energy solutions, thus enhancing the sustainability of food systems and contributing to broader climate goals.

Access to durable and high-quality technologies:

The second priority need, identified by 50.12% of respondents, was access to high-quality and durable technologies. This highlights a critical barrier in the widespread adoption of improved household energy technologies, as many users may be skeptical about the longevity or reliability of these technologies. To address this barrier, FOLUR's initiative should focus on facilitating access to affordable, durable, and locally appropriate technologies that can be integrated into farming practices, cooking, and land restoration activities. Ensuring that rural and farming communities have access to reliable, clean energy technologies is essential for improving household energy efficiency and reducing deforestation particularly in areas where forest resources are being depleted at unsustainable rates.

Durable, high-quality technologies such as solar-powered irrigation systems and efficient cookstoves can significantly reduce environmental pressures from traditional energy sources while supporting more resilient agricultural systems.

Financial services and credit access:

The third priority need identified by 31.43% of respondents is financial services (credit). Access to finance is often a significant barrier to the adoption of new technologies, including renewable energy solutions. Integrating financial services and microcredit programs into the FOLUR framework can help provide smallholder farmers and rural communities with the necessary financial resources to invest in energy-efficient technologies and sustainable practices. This would significantly reduce the financial barriers that prevent many from adopting cleaner energy alternatives.

Fair pricing and technical guidance:

In addition to training and access to durable technologies, fair pricing of energy technologies (ranked as the second priority by 23.18% and the third by 11.03%) and regular technical guidance (ranked as the third priority by 10.60%) also emerged as key needs. These findings support FOLUR's broader goal of ensuring that sustainable technologies are not only accessible but also affordable and supported by ongoing technical guidance. Fair pricing is essential for ensuring that smallholder farmers can transition to renewable energy technologies without compromising their financial stability. Moreover, providing technical guidance can help users maximize the benefits of these technologies by ensuring they are properly maintained and used effectively, thus ensuring their long-term success and sustainability. These priorities align with findings from rural Ethiopia showing that knowledge, access, and affordability strongly influence engagement with renewable energy solutions (Tesfay et al., 2024; Shallo & Sime, 2025).

4. Conclusion

The findings of the study reveal a critical reliance on traditional biomass fuels for household energy, with drywood being the dominant source for both cooking (94.54%) and baking (64.53%). Despite some degree of energy self-provisioning, particularly in drywood collection, a significant portion of households still rely on community and government forests, exacerbating deforestation and environmental degradation. Charcoal and crop residues also contribute notably to household energy consumption. However, the adoption of cleaner, more sustainable energy alternatives remain strikingly low, with *butagas* usage for cooking at a mere 0.30%.

This heavy reliance on traditional biomass fuels presents a key challenge for the regions, but it also highlights a significant opportunity for intervention. The FOLUR project can play a pivotal role in promoting clean and renewable energy solutions, particularly through the expansion of Improved Cookstoves (ICS), which are currently used by just 10.99% of households. ICS, such as the Mirt stove, have a proven potential to reduce pressure on forests by enhancing fuel efficiency, saving time, and improving health outcomes. Despite these benefits, barriers such as limited awareness, product durability, high costs, and technical complexity hinder broader adoption. Non-users are primarily deterred by limited awareness and availability of affordable options, while users cite firewood saving, time savings, and health benefits as key motivators for adoption.

The low adoption rate of biogas (0.76%) also signals the potential for clean energy interventions, particularly for cooking and lighting. However, the high initial costs, limited awareness, and insufficient access to necessary materials are significant obstacles to scaling up this technology. Similarly, solar energy use is more prevalent (39.75%) but remains predominantly limited to lighting and heating, with minimal application in cooking. The lack of grid electricity access (81.09% of households) further complicates the situation, underscoring the need for alternative energy solutions like solar to reduce reliance on traditional biomass.

Household energy strategies in FOLUR areas are determined by gender, education, household composition, livelihood activities, household income from beekeeping and resource accessibility. Traditional biomass fuels remain essential due to affordability and availability, even as some households transition to commercial fuels or clean technologies. Adoption of alternative energy technologies is higher among male-headed, educated, and environmentally conscious households, while female-headed households or those with abundant land or reliance on traditional fuels are less likely to adopt new technologies. Complementarity between fuels and technologies highlights the coexistence of traditional and modern energy systems rather than a complete transition.

Projections of future household energy demand show that traditional fuels such as drywood, charcoal, and kerosene will continue to dominate in the coming years, but there is also an anticipated exponential growth in the adoption of fuel-saving technologies, including ICS, biogas, solar, and grid electricity. With an expected 20% annual growth rate, these technologies could see adoption rates that surpass 2,300,000 households within 15 years. ICS is expected to remain the most widely adopted technology due to its affordability and compatibility with local cooking practices, while biogas and solar technologies will experience steady growth, particularly in semi-urban and rural areas. However, grid electricity adoption remains limited, highlighting the need for infrastructure development and rural electrification efforts.

5. Recommendations for targeted interventions

To accelerate the transition from traditional biomass fuels to clean energy alternatives, the following interventions are recommended:

Policy support and advocacy: Strengthening government policies that support renewable energy adoption is essential. This includes subsidies, tax incentives, and regulatory frameworks that promote the adoption of clean technologies like ICS, biogas, and solar. Policies should also address the affordability and accessibility of these technologies, particularly for rural and low-income households.

Financial support and innovative financing models: Given the high upfront costs associated with clean energy technologies, financial mechanisms such as microfinance, low-interest loans, and subsidies are crucial. These financial tools should be targeted at rural and underserved communities to ensure equitable access to clean energy solutions. The development of pay-as-you-go systems for solar and other renewable technologies could also help lower financial barriers.

Awareness and capacity building: Public awareness campaigns are vital to inform households about the benefits of adopting cleaner energy solutions, especially in areas with low current adoption rates. These campaigns should focus on demonstrating the health, economic, and environmental benefits of fuel-efficient cookstoves, biogas, and solar technologies. Capacity-building initiatives should train local entrepreneurs and technicians to maintain and repair these technologies, ensuring their long-term viability and reducing reliance on external support.

Technology accessibility and product innovation: To improve the adoption rate of clean energy technologies, the FOLUR project should focus on enhancing the durability and affordability of technologies like ICS and biogas. Collaboration with local manufacturers to improve product quality, as well as facilitating bulk procurement to reduce costs, could make these technologies more accessible. Additionally, introducing more affordable and culturally compatible solar cooking solutions would help overcome current barriers to solar energy adoption for cooking.

Community engagement and local leadership: Engaging local leaders and community organizations in the promotion of clean energy technologies is essential for fostering trust and increasing adoption rates. Community-based demonstrations of ICS, biogas, and solar systems can help dispel myths, build trust, and encourage local households to adopt these technologies. Support from local government and NGOs will also be critical in ensuring the success of these initiatives.

Wider promotion of alternative energy: Governments and stakeholders should raise awareness through national campaigns on the benefits of renewable energy like solar, and biogas. Incentives such as low-interest loans should be provided to encourage investment. Public-private partnerships can help expand renewable infrastructure, while community demonstration projects can showcase success stories. Supportive policies for off-grid systems and use of locally made technologies can further boost adoption.

Local production and supply: Encouraging local manufacturing of renewable energy equipment reduces costs and dependency on traditional energy. Technical training programs should be developed to build local expertise in production, installation, and maintenance. Governments can support SMEs with micro-financing. Establishing local service centers ensures reliable maintenance and availability of spare parts. Implementing quality standards will help maintain trust in local products.

Establishment of cooperatives: Energy cooperatives can empower communities to produce, manage, and distribute renewable energy locally. Training in cooperative management, finance, and technical maintenance is essential. Access to cooperative-based credit schemes can help communities invest in renewable systems. Encouraging women's and youth participation in energy cooperatives promotes inclusion and job creation. Partnerships with local authorities and private investors can strengthen their operations.

Market linkage and distribution: Developing market linkages helps connect local producers with buyers and distributors. Digital platforms can promote renewable energy products and services to wider audiences. Partnerships between cooperatives and large firms can integrate local production into national supply chains. Financial institutions should offer green financing and leasing options to make renewable technologies more accessible.

Promote gender-inclusive energy programs: Empower women through access to finance, information, and decision-making to increase adoption of improved cookstoves, biogas, and solar systems.

Enhance education and awareness: Conduct campaigns on health, economic, and environmental benefits of clean fuels and technologies, particularly targeting less educated households.

Encourage integrated technology adoption: Promote combined packages of improved cookstoves, biogas, and solar to leverage complementarity and optimize efficiency.

Support resource-constrained households: Provide micro-financing, subsidies, or group purchasing schemes to facilitate uptake among households with limited income, land, or energy access.

Link energy adoption to livelihoods and forest conservation: Emphasize how technology adoption supports forest conservation, livestock productivity, and overall sustainability, appealing to environmentally conscious households like beekeepers.

Promote fuel-saving and renewable solutions: Introduce improved stoves, biogas, and solar systems to reduce reliance on traditional biomass, mitigate deforestation, and improve household energy security.

Monitoring, evaluation, and feedback loops: Implementing robust monitoring and evaluation mechanisms is essential to track the progress of clean energy adoption and address any emerging challenges. Feedback loops should be established to continuously assess the effectiveness of interventions and adjust strategies accordingly. The FOLUR project should also collect data on the impact of clean energy adoption on deforestation, household well-being, and environmental sustainability to showcase the benefits of these technologies and justify further investments.

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