Adoption of improved cook stoves by households in informal settlements of Woreda 12, Yeka subcity, Addis Ababa

Nibretu Kebede1*, Degefa Tolossa2 and Tamirat Tefera1

Abstract

Background: This study analyzed the factors affecting the use of improved cook stoves (ICS) in informal settlements of Addis Ababa based on the data generated from 450 households drawn from Woreda (Woreda is a local term used to describe the lowest administrative unit of Addis Ababa City Administration, Ethiopia.) 12 of Yeka subcity. It examined the interactive effect of households’ socio-economic backgrounds and energy sources on the adoption of ICS. The data were analyzed using descriptive methods and the multinomial logit model.

Results: Demographic and economic factors such as sex of the household head, family size and family income have no relationships with households’ ICS use while education level, number of years lived in the area, type of home owned, and stove-operating costs have a significant influence on the choice of an ICS. Households that live in a good home (made from wood and cement) used more Mirt (Mirt is an improved firewood stove mainly used to bake Injera and bread.) and Lakech [Lakech also called Tikkil is an improved charcoal stove used to cook different kinds of dishes (non-Injera)] stoves than the traditional three-stone stoves. On the other hand, household heads with higher levels of education and who have lived more than 7 years in the area in a better home owned more ICS than the traditional three-stone stoves.

Conclusions: The availability, affordability, durability and simplicity to operate stoves, and subsidies affect the choice of an ICS. Energy sources that are commonly used by households in informal settlements also have a strong influence on the choice of energy-efficient stoves. Compared to ICS, heavy use of traditional three-stone stoves by households that already have access to electricity, directs government policies to focus on providing reliable electric service and subsidize those using ICS.

Keywords: Informal settlement, ICS, Lakech stove, Mirt stove, Three-stone stove, Addis Ababa

Background

Energy-efficient cooking technologies or simply ICS increase energy efficiency [1], reduce heavy reliance on fuel wood and energy consumption levels, and save cooking time [2, 3]. They improve the taste and flavor of food and the quality of life [4–6]. Likewise, they help to manage demand and save energy by replacing conventional energy technologies [7], efficiently convert biomass into energy, emit very little smoke associated with complete combustion, and contribute to the sustainable use of scarce resources [8–10]. Switching to modern stoves and fuels and using ICS with better technological designs transforms lives by improving health, protecting climate and environment, empowering women, lowering households’ expenses on medicines; reducing the workloads and the quality of life [4–6]. Likewise, they help to manage demand and save energy by replacing conventional energy technologies [7], efficiently convert biomass into energy, emit very little smoke associated with complete combustion, and contribute to the sustainable use of scarce resources [8–10]. Switching to modern stoves and fuels and using ICS with better technological designs transforms lives by improving health, protecting climate and environment, empowering women, lowering households’ expenses on medicines; reducing the workloads and the quality of life [4–6].

© The Author(s) 2022. Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.
of women and children; and improving flexibility for women with regard to labor, time and money [11–13].

Projections for 2030 indicated that aggressive energy efficiency measures can significantly reduce the demand for energy. For instance, a study conducted by Reyna and Chester [1] indicated that the adoption of light-emitting diodes (LEDs) reduces residential electricity consumption for lighting by 53%, and that upgrading electrical appliances could lower it by 28%, and replacing light bulbs and incandescent lamps with more efficient compact fluorescent lamps could lower residential electricity consumption for lighting by 75%, ICS reduce firewood consumption by 40–60% and charcoal use by 30–40% compared to traditional stoves [11, 14, 15]. Such energy-efficient technologies can produce the same amount of light with less energy and expense of firewood whereas traditional stoves are likely to break easily when moved from place to place [6, 16]. High storage capacity batteries and solar panels are also useful, resilient and clean energy sources used in all geographical areas [15, 17].

The multi-tier framework (MTF) developed by the World Bank provided a comprehensive guide to analyze the factors affecting households’ choice of energy-saving stoves. These factors are availability of energy sources, uninterrupted power supply, durability and affordability of the stove, price of fuel, the capacity to load big appliances, the health and safety of using the stove, and the formality of the service provided [18]. In line with this, Yonas, Abebe, Köhlin, and Alem [19] found that as income increases, households are more likely to buy ICS that lower energy cost and use clean energy sources. Medina, Cámar, and Monrobel [20] and Amoah [21] also suggested that substituting declining biomass, adopting energy-efficient stoves and changing households’ energy consumption behaviors are effective tools to achieve economic outcomes and lower environmental pollution.

However, studies indicated that limited supply and high cost of energy-efficient stoves at local levels, shortages of electric meters, unavailability and high cost of spare parts, lack of access to credit facilities, and spending priorities for other basic needs affect the use of energy-efficient technologies [22–27]. The cost of fulfilling ICS and cooking appliances is capital intensive and unaffordable. Padam et al. [18] underlined the importance of providing incentives and arranging flexible payment systems and credit facilities. A study compiled by Mfumus and Commeh [7] indicated that socio-cultural, behavioral and competence-related barriers also make the adoption of ICS technology socially unacceptable at the household level. For example, youth in Botswana have made collecting fuel wood and making fire part of their culture. Some of them do not even recognize the indoor air pollution effects of traditional stoves, firewood savings and the health benefits of using ICS [28, 29]. Feldmann and Otremba [15] and Chagunda, Kamunda, Mlatho, Mikeka, and Palamuleni [3] described that households prefer to use traditional three-stone stoves over power-saving technologies whilst food such as Injera\(^1\) baked on an ICS does not smell smoky, has good taste, and the edges are smooth [30].

48.27% of the total population has access to electricity in Ethiopia, with a current production of 4284 MW, where the domestic energy consumption amounted to 92% of the energy supply, where waste and biomass are the primary sources of energy amounting to 92.4% of Ethiopia’s energy supply, whereas 84% of urban households used biomass, and 63.3% used traditional three-stone stoves as their primary stove [18, 30–33]. The use of stoves such as flat Mitad\(^2\) and Fermelo\(^3\) requires low initial cost, which is highly consistent with consumers’ preferences, i.e., ease of use and relatively wide availability [25]. The cost of cooking appliances such as kittles, flat Mitad and pots are cheaper and the technology is more easily adaptable than electrical items such as electric ovens, toasters and water boilers. Culturally, people like to see open fire and be around it, smoke makes food smell nice, and women like to go out collecting fuel wood as it gives them a space to socially interact [7]. Traditional three-stone stoves can be easily set up, fit all pot sizes, the heat from the fire provides warmth, light, a sense of comfort and the use of biomass is often the only available, accessible and affordable fuel for most households [15]. On the other hand, traditional open fire cook stoves are not fixed in one place and when these stoves move from place to place, the risk of breakage is high.

However, heavy reliance and inefficient usage of biomass in open fire burning wastes resources and overconsumption of biomass causes many harmful impacts that impede economic and social development in developing countries [13, 34, 35]. According to WHO, inefficient combustion of solid fuels in low-quality open fire and outdated stoves, operated in poorly ventilated kitchens and excessive exposure to smoke impact the health of women and children [12, 18]. It causes 4 million deaths and produces 1 gigaton of CO\(_2\) emissions every year from burning wood fuels [11]. Globally, it resulted in severe respiratory diseases responsible for up to 12% of deaths in Ethiopia, makes clothes dirty and smells like

---

1. Injera is flatbread traditional staple food made from fine iron-rich Teff (agricultural product typically grown in Ethiopia) sometimes mixed with wheat, barley or sorghum flour.
2. Mitad is a three-stone traditional stove used to bake Injera (staple food in Ethiopia) using fuel wood, plant residues and animal dung.
3. Fermelo is a stove used to cook dishes using charcoal in an open fire.
smoke, irritates eyes and creates a sense of discomfort [30, 36]. Burning biomass in such stoves has undesirable consequences to the environment such as the decline in the availability of biomass resources, deforestation, and greenhouse gas emissions contributing to climate change. Most studies indicated that households will continue to depend on these fuels for decades to come [30].

Whilst ensuring access to affordable, reliable, sustainable, clean, safe, healthy and modern energy for all by 2030 is one of the 17 Sustainable Development Goals of the UN, only 4.1% of households in Ethiopia use electricity as a primary cooking fuel [18]. Energy sources such as biogas and Liquefied Petroleum Gas (LPG) are rare, accounting for less than 1% of households and are unaffordable [18]. Similarly, although solar energy is easily available, clean, and very effective to prepare staple foods, generating electricity using these sources is a recent practice in Ethiopia. Beyond this, not all traditional dishes can be prepared with solar energy, and solar cookers are also expensive to use. As a result, the government has prioritized the use of ICS and efficient lighting as the most important areas to guide investments, expand energy supply, and ensure environmental sustainability [37].

Classification of ICS based on fuel use, portability in the kitchen and different sizes is also essential in the choice of stoves [15, 35]. For example, Mirt stoves using firewood to bake Injera, are designed to reduce environmental degradation whereas Lakech stoves use charcoals. Disregarding the facts that the performances of these stoves are evaluated mainly by the amount of generated energy which is absorbed by the cooking pot (heat-transfer efficiency) and the amount of generated energy which is converted to heat, as well as the amount of carbon dioxide which is developed (combustion efficiency) [38], household members use these stoves for preparing different kinds of foodstuffs.

Lack of access to legal land entitlement forces households to construct houses below the standard and becomes the major impediment to get access to electricity. This in turn forces many households to use open fire traditional three-stone stoves while wealthy and educated households are likely to adopt energy-efficient stoves. Many studies focused on alternative energy sources, the available technologies and the deteriorating living conditions of households in rural and urban areas of Ethiopia [19, 39–41]. However, in Ethiopia, little has been done for the adoption of energy-efficient stoves in informal settlements.

This study addressed the questions: (1) What kind of stoves households own in informal settlements? (2) What factors attribute to the adoption of ICS? (3) How energy sources and households‘ socio-economic backgrounds affect the adoption of ICS? The study considered households‘ socio-economic and demographic characteristics, financing options such as credit facilities and subsidies affecting the choice of energy-efficient stoves.

The study is set in four sections: the first section provides the background of the study followed by a section that explains the data and methods used. The second section begins with a description of the study area, how the sample is designed, and then data collection and analysis methods employed follow. The third part presents the results of the study and discusses the findings. The final section provides conclusions, implications and future research directions in the area.

Data and methods
Description of the study area
Like other developing cities, the city of Addis Ababa is faced with multiple development challenges. The city is expanding in a sprawling manner, and around 30% of the population lives under poor living conditions [42]. It has ten subcities and four of them are found in the downtown town of the city while the rest border rural areas (Fig. 1). Among the six subcities found in the outreach areas of Addis Ababa, informal settlers in Yeka subcity are settled in ragged areas, live close to forests and the subcity borders are far from the surrounding region. This situation has caused researchers to focus on this subcity.

Woreda 12 is one of the 13 districts in Yeka subcity that shares the largest territory with the cultivated edge of rural areas. It is located at about 9°3’2"N, 38°52’41"E, 2450 m above sea level, is found approximately 11 km from the city center and is situated around the holy church of Kotebe Gabriel and Kotebe Metropolitan University. Based on the data compiled from surveys conducted in the study area, 78% of informal settlers have access to roads and transportation, 80% to education and health centers, 20% live around river banks and low lying areas, 47% live close to forest resources and 38% are located in a rugged topography. Informal settlers are in particular located in Kotebe Gebriel, Hibret Amba, Rediet, Happy Village, Mesalemia, Sara Park, Kara and Demamit sites.

Sample design and sampling method
Considering the existence of a very large number of informal settlers and their similarity on the one hand, and the difficulty to cover all sites in a limited time and financial constraints, on the other, have forced the researchers to down-scale the sample design to the household level and subdivided respondents in three stages.

First Yeka subcity was purposively selected among the ten subcities in Addis Ababa and Woreda 12 was purposively selected among the 13 districts in Yeka subcity due to its location in the expansion/outreach areas.
Fig. 1 Location map of the study area. Source: modified from EthioGIS shape file
and longest territory which it shares with a neighboring region relative to the other districts in the subcity.

Second In Woreda 12, there are eight sites and 2,590 informal settlers officially registered by the local administration. From these households, 1926 are electric users\(^4\) found in seven sites and 664 are non-users\(^5\) of electricity found in three sites. This number is still very large and researchers cannot cover all of them. Instead, it served as a sample frame to select specific study sites and respondents using purposive and random sampling strategies, respectively. As a result, two sites from electric users (that is, Kotebe Gebriel and Hibret Amba with a total of 576 informal settlers) and two sites from non-users of electricity (that is, Kotebe Gebriel and Demamit with 516 informal settlers) were selected purposively. This helped to develop a balanced sample frame to choose electric users and non-users of electricity.

Finally Once the sample frame is specified, the representative sample sizes for the study were drawn randomly considering the relative heterogeneity among the sites, and the relative homogeneity among households within the same site was determined with a 95% confidence interval and 450 sampling units (comprising 229 electric users and 221 non-users of electricity). However, due to a lack of legal living status of informal settlers, strict randomization was not possible to select households for the study. To minimize the effects of this problem, respondents were selected using a proportional sampling method that gives equal opportunity to each household in both electric users and non-users of electricity groups.

Data sources and analysis methods

Primary data were obtained using a multi-tier questionnaire that helped to capture information about households’ energy sources and factors affecting energy choice. The questionnaire was structured to cover households’ socio-economic characteristics, food consumption behavior, energy-saving stoves owned, the reasons for adopting the stoves that are currently owned, the adoption level of ICS and the challenges encountered in using energy-efficient technologies. The questionnaire was administered to 450 randomly drawn households found in Kotebe Gebriel, Hibret Amba and Demamit representing 2,690 informal settlers. The survey was managed by the researcher and properly selected, well trained and closely supervised enumerators. The list of informal settlers that served as a sample frame was obtained from the computerized data base of Woreda 12 Administration.

Field work during the pilot study and data gathering stages helped to observe the housing conditions, the landscapes, availability of infrastructures in the study area and to closely monitor the activities of data collectors. To minimize distortions and personal biases associated with respondents’ opinions and attitudes, the validity and reliability of the data gathered was verified carefully using statistical software. However, due to a lack of legal living status of informal settlers, strict randomization was not possible and some settlers were even reluctant to fill in the questionnaire or unavailable during surveys. Those problems were managed and the margin of errors was minimized by substituting them by others using the nearest neighborhood approach.

Descriptive statistics, such as frequency tables, percentages, bar graphs and figures, were used to present and analyze the influence of demographic variables affecting ICS use, to explain the relationship between the duration of ICS adopted by households and fuel consumption trends, to discuss alternative methods of financing energy-efficient stoves and factors affecting the adoption of ICS, to explain the conditions to use solar and electric stoves, and to present the rationale for using ICS and to describe the major problems that households in informal settlements encountered.

The multinomial logit model was used to analyze the adoption of energy-efficient cooking stoves in informal settlements. It combined a set of factors affecting the choice of energy-efficient stoves. To analyze the determinants of ICS use, the dependent variable is households’ alternative cook stoves (the traditional three-stone stove, Mirt, Lakech and electric stoves) and explanatory variables are developed based on the theoretical frameworks and expected to influence households’ usage of energy-efficient stoves. The model that integrates these variables and helps to interpret the effects of a set of explanatory variables with regard to the adoption of energy-efficient technologies is provided as follows:

\[ Y_i = \delta_i + \beta_1 X_1 + \beta_2 X_2 + \cdots + \epsilon_i, \]

where \( Y_i \) is the outcome variable for a household adopting energy-efficient technologies (such as power-saving electric stoves and improved biomass stoves like Lakech and Mirt); \( X_i \) are explanatory variables that includes demographic, economic and stove-related factors; \( \delta_i \) and \( \beta_i \) are parameter estimates; \( \epsilon_i \) are error terms.

\(^4\) Electric users are households using electric power for cooking and baking in addition to lighting. They obtained electric power from the Ethiopian Electric Utility Company legally or from their neighbor by sharing electric cost.

\(^5\) Non-users of electricity refer to households who either use electric power from their neighbors only for illumination purpose or those who do not use it at all.
Results and discussion

Factors affecting energy-efficient stove use: descriptive analysis

Table 1 provides the stoves owned by households based on their socio-economic profiles. The order of these stoves is presented based on their energy efficiency level. As provided by Yonas and et al. [19] and Zenebe et al. [43], this order spans from the traditional three-stone stoves with the lowest technology level through improved biomass stoves (Mirt) and charcoal stoves (Lakech) to electrical stoves with advanced technology.

The survey result indicated that 20% of households in informal settlements used open fire traditional three-stone stoves, 42% Mirt/Lakech stoves and 38% electric stoves as their primary cooking stove. Male and female headed households considered in this study are 63% and 37%, respectively. About 13% of male headed households and 7% of female headed households used traditional three-stone stoves; 29% males and 13% females used Mirt/Lakech stoves; and 21% males and 17% females used electric stoves. However, although the number of males is greater than that of females in all cases, it is difficult to exhibit a clear relationship between sex of the household head and the adoption of energy-efficient stoves.

In terms of family size, the number of households using traditional three-stone stoves has increased from 3% (below 3 families) to 9% (above four families) whilst the number of households using ICS (Mirt/Lakech and electric stoves) varies considerably with an increase in family size. This indicates that family size does not affect the households efficient stove use. However, studies conducted by Bekere and Megerssa [44], Geddafa, Melka, and Sime [45] and Woubishet [46] indicated that sex of household head and family size are important determinants in adopting Mirt stoves and biogas technology.

In fact, the findings of Bekere and Megerssa [44], Geddafa, Melka, and Sime [45], in particular, are based on the adoption of biogas technology and Mirt stoves in rural areas, but not in informal settlements.

Among married household members that constitute 78% of all household members, 35% used electric stoves and 28% Mirt/Lakech stoves. This shows that married

| Demographic and socio-economic factors | 3-stone stove | Mirt/Lakech stove | Electric stove | Total |
|---------------------------------------|--------------|-------------------|---------------|------|
| Sex                                   |              |                   |               |      |
| Male                                  | 13           | 29                | 21            | 63   |
| Female                                | 7            | 13                | 17            | 37   |
| Total                                 | 20           | 42                | 38            | 100  |
| Family size                           |              |                   |               |      |
| Below 3 families                      | 3            | 4                 | 5             | 12   |
| 3–4 families                          | 8            | 22                | 24            | 54   |
| More than 4                           | 9            | 15                | 10            | 34   |
| Total                                 | 20           | 41                | 39            | 100  |
| Marital status                        |              |                   |               |      |
| Not married                           | 4            | 11                | 3             | 18   |
| Married                               | 15           | 28                | 35            | 78   |
| Separated                             | 1            | 2                 | 1             | 4    |
| Total                                 | 20           | 41                | 39            | 100  |
| Education                             |              |                   |               |      |
| Below grade 4                         | 3            | 6                 | 0             | 10   |
| Grade 4–8                             | 6            | 11                | 4             | 21   |
| Grade 9-Diploma                       | 8            | 14                | 8             | 30   |
| Degree and above                      | 2            | 10                | 27            | 40   |
| Total                                 | 20           | 41                | 39            | 100  |
| Family income per month               |              |                   |               |      |
| Up to 6000 Birr*                      | 7            | 16                | 4             | 27   |
| Above 6000 Birr                       | 13           | 25                | 35            | 73   |
| Total                                 | 20           | 41                | 39            | 100  |
| Years lived in the area               |              |                   |               |      |
| Up to 3 years                         | 5            | 9                 | 2             | 16   |
| 4–6 years                             | 6            | 11                | 8             | 26   |
| 7–9 years                             | 3            | 11                | 9             | 23   |
| Above 9 years                         | 5            | 10                | 20            | 35   |
| Total                                 | 20           | 41                | 39            | 100  |
| Home type /condition                  |              |                   |               |      |
| Poor (wood and mud)                   | 9            | 11                | 4             | 24   |
| Good (wood and cement)                | 10           | 30                | 30            | 70   |
| Very good (steel and blocket)         | 0            | 1                 | 5             | 6    |
| Total                                 | 19           | 42                | 39            | 100  |
| Number of dwellings                   |              |                   |               |      |
| 1–2 rooms                             | 12           | 18                | 7             | 37   |
| Three rooms                           | 4            | 15                | 13            | 31   |
| More than 3 rooms                     | 3            | 10                | 18            | 31   |
| Total                                 | 20           | 42                | 38            | 100  |

Source: Survey data, March 2022. *Birr is the local currency of Ethiopia. Its official exchange rate in February 2022 was 1 USD = 51 Birr
people are more likely to use ICS than singles. Likewise, higher levels of education of the household head and longer living periods in the area have a positive influence on the adoption of ICS. Income wise, from households earning below 6000 birr/month, 7% use traditional three-stone stoves and 20% ICS. From those earning above 6000 birr/month, 13% use traditional three-stone stoves and 60% ICS. In both cases, a significant number of households preferred to use ICS indicating that the relationship between family income and stove choice is not clearly described while Sheng, He and Guo [34] and Woubishet [46] concluded that wealth and income are important determinants to adopt ICS.

Informal settlers with existing access to electricity were expected to use electric stoves. But only 73% were found using electric stoves and the rest used traditional three-stone stoves and ICS. From electric users, 72% were found using Mirt or Lakech stoves mainly due to a lack of adequate and reliable electric supply.

The relationship between home conditions (described by the type of home owned) and number of dwellings owned and energy-saving stoves adopted by the households is also clearly depicted in Table 1. Among households living in a good house (made of mud and cement) only 10% used traditional three-stone stoves while 60% used Mirt/Lakech and electric stoves. From households living in very good houses (made of steel and blockets), households using traditional three-stone stoves is literally nil while those using ICS are 6%. Similarly, among households who live in 1–2 rooms, 12% used the traditional three-stone stoves and 25% used ICS. From those who owned more than 2 rooms, only 7% used traditional three-stone stoves while 55% used Mirt/Lakech and electric stoves. These results suggest that home conditions and number of rooms in a home determine households ICS use and as the number of rooms and the conditions of houses owned by households improves, the tendency of those households using energy-efficient stoves increase. This finding is similar to that reported in [46].

Figure 2 presents the typical Mirt stove used by households in Ethiopia to bake Injera and bread. Compared to the traditional three-stone stove tripod, it saves fuel wood from 22 to 31% [41].

In Ethiopia, ICS were primarily designed to solve deforestation problems and pollution effects. They are keys to safe, reliable, affordable and sustainable energy in the future and balance energy scarcity [47, 48]. However, in this study, 50% of households used these stoves to reduce the operational cost of energy by efficiently utilizing biomass and reducing wastages, 31% to save time and reduce workloads of family members involved in cooking activities, and 18% to protect forests and sustainably use scarce resources. This is in line with the research results described by Abebe & Koch [35] and Dawit [49] who emphasized households’ economic reasons to own energy-efficient cooking stoves and shift to renewable energy sources.

Households were required to rate the salient factors that affect their choice of stove based on the most pressing reasons being provided to them. Table 2 presents the five most important factors that influenced households’

| Stove type      | Factors affecting stove choice                  | Percent |
|-----------------|-------------------------------------------------|---------|
| Three-stone stove | 1. Cheap technology to buy                      | 43      |
|                 | 2. Widely available stove                       | 39      |
|                 | 3. Well-known stove                             | 8       |
|                 | 4. Lowers the cost of energy                    | 6       |
|                 | 5. Simple/easy to use                           | 4       |
| Mirt stove      | 1. Most subsidized and easy to obtain credit    | 33      |
|                 | 2. Quality and durability of stove              | 25      |
|                 | 3. Lowers the cost of energy                    | 21      |
|                 | 4. Well-known stove                             | 11      |
|                 | 5. Widely available stove                       | 10      |
| Lakech stove    | 1. Lowers the cost of energy                    | 25      |
|                 | 2. Quality and durability of stove              | 25      |
|                 | 3. Most subsidized and easy to get credit       | 19      |
|                 | 4. Widely available stove                       | 16      |
|                 | 5. Cheap technology to buy                      | 16      |
| Electric stove  | 1. Clean and health source                      | 24      |
|                 | 2. Saves family labor and time                  | 23      |
|                 | 3. Convenient and easy to use                   | 21      |
|                 | 4. Well-known stove                             | 18      |
|                 | 5. Quality and durability of stove              | 14      |

Source: Survey data, April 2020
decision to own a specific stove. Based on this data, 82% households use traditional three-stone stoves influenced by the availability and price of the stove, 79% prefer to use Mirt stoves due to the availability of subsidies, credit facilities, quality/durability and efficiency reasons; and 69% owned Lakech due to its capacity to lower energy cost, durability of the stove, the availability of subsidies and credit facilities. The choice of electric stoves depends mainly on cleanliness, contribution to minimize indoor air pollution, capacity to save family labor and time, and simplicity and convenience to use the stove technology as confirmed by 68% of households. In relation to this, Feldmann & Otremba [15] concluded that availability, affordability and reliability of fuels and the contribution of stoves to clean burning, the purchasing price of the stove and simplicity to use determines the choice of ICS.

**Duration of ICS adopted by households and fuel consumption trends**

To better understand the adoption rate of ICS in informal settlements, data are captured from 390 households. Based on this data, 55% are electric users and 45% are non-users of electricity. Depending on the source of energy, about 87% of households owned only one type of stove and others owned two or more kinds of cooking stoves. Figure 3 presents the time when households owned energy-saving stoves (that is, 8% owned before 10 years, 40% before 5–10 years, and 51% in the past 5 years). Based on this data, the adoption of ICS increased greatly in recent periods and the rate of adoption of electric users is greater than that of non-users. As corroborated by Abebe & Koch [33], the adoption speed of ICS also increased with the increased income and varies across regions.

It is also essential to understand the perception of households on fuel consumption trends and the forces that drive them to adopt ICS. The result showed that both electricity and biomass users contend that their consumption levels either remained the same as before or increased over time. Specifically, 22% of biomass users and 42% of electric users perceive that energy consumption has grown significantly whilst 21% of biomass users and 9% of electric users contend that there is no change in energy use over time. In both cases, households are either forced to expend extra cost for energy sources or use ICS with the intent of reducing operation costs. Biomass users in particular should adopt ICS use and focus on shifting to modern energy sources.

**Financing sources and challenges to use energy-efficient stoves**

Households have alternative financing methods to own energy-efficient stoves. In the study area, about 47% of stoves are owned from own source through upfront payment, 32% were obtained through subsidies and discounted sales, 15% through suppliers’ credit and loans from creditors, and 6% freely and a mix of financing options (Fig. 4). The sources of finance also vary based on household’s electric use status. For example, 27% of electric users obtained a stove via own sources and 6% through an installment basis while this figure amounted to 20% and 9%, respectively, for non-users of electricity. This indicates that unless special arrangements such as subsidies and discounts, incentives and credit facilities should be provided to the low-income households, as they cannot afford to pay the upfront cost of energy-efficient stoves like cylinders, electric stoves and expensive electrical appliances.
Many households believe that subsidies and credit facilities help them to install energy-efficient stoves and enjoy the economic and health benefits of switching to clean energy sources. They also contend that the risk of unreliable electricity supply urges them to own more than one kind of stoves and adopt an energy-stacking approach. On the contrary, a not very low number of households (about 30%) believed that the removal of subsidies could result in the increase of energy prices, and urging polluters to pay for their pollution effects, encourage households to use energy-efficient cooking stoves and discourage the consumption of traditional energy sources. The risk of unreliable electricity supply also urges households to own more than one kind of stove and adopt an energy-stacking approach.

However, although 38% of households described that they had no problems in using energy-efficient stoves, 62% believed that they faced different challenges (Table 3). Specifically, about 22% were faced with the high cost of obtaining ICS, 12% encountered a lack of maintenance service, 12% described that the stoves are poor in quality, do not last long and are poor in workmanship, and 6% explained that the stoves could not power large appliances. These problems shall require the attention of ICS suppliers, creditors, donors and government bodies. According to Wassie & Adaramola [50], the provision of poor-quality, high cost of solar PV systems, lack of after-sales service, and limited access to credit facilities are critical problems in applying ICS.

The use of solar energy and electrical appliances
In urban Ethiopia, the usage of solar energy for domestic application is a recent practice and the least utilized resource. According to Hailu and Kumsa [51], the country uses off-grid solar photovoltaic (PVs) technologies such as distance-education through radios and vaccine fridges in remote areas. Where other fuels are not easily available, it is a useful source of energy for lighting and preparing staple foods. However, the current energy mix in Ethiopia is dominated by hydropower. Projections indicate that this mix will shift to solar and wind energy towards the end of 2050 as a least-cost energy supply option [52]. In rural Ethiopia, electricity has reduced kerosene use, health damages, CO₂ emissions and helped micro enterprises to generate more business income [50].

In this study, 60% of households used solar energy exclusively for lighting and charging batteries. Solar cookers are too expensive, not widely available, and influenced by cultural factors. On the other hand,

| Problems encountered to use ICS | Freq | % |
|---------------------------------|------|---|
| 1. No problem encountered till now | 172  | 38|
| 2. Expensive to buy | 96   | 22|
| 3. Absence of maintenance service | 55   | 12|
| 4. Not durable/poor in quality stoves/ | 53   | 12|
| 5. Cannot power large appliances | 27   | 6 |
| 6. Other reasons | 47   | 10|
| Total | 450 | 100|

Source: Survey data, Feb., 2022
traditionally, all dishes cannot be prepared with it. That is, solar energy does not completely replace traditional fuels and stoves [15]. All these facts have forced households in informal settlements to prioritize electrical appliances according to their income level and importance of appliances for a household (Fig. 5). In view of this, 60% want to own baking and cooking devices, 21% entertainment devices (such as television and radios), 8% refrigerators, and 4% power-saving lumps and chargers as their priority choice. Household members mainly need baking and cooking stoves to fulfill their basic needs, reduce costs of energy not only associated with an increasing biomass price but also with the cleanliness or healthy nature of electricity and solar energy.

In terms of the frequency of stove use, 37% of electric users used electric stoves regularly while 21% used them only occasionally. The latter group used electric stoves sometimes due to a lack of adequate, reliable and affordable electricity supply and shortages, as well as the high price of stove technologies. To cope with these problems and cushion sudden electricity interruption, 28% were found to use traditional three-stone stoves always and 14% only sometimes. The absence of reliable supply and the use of biomass by households who have existing access to electricity, however, exacerbate increased deforestation and indoor air pollution.

The use of ICS in informal settlements: the multinomial logit approach

This section presents various factors that have a potential impact on the choice of ICS in informal settlements. These factors were considered separately in the descriptive analysis. However, multinomial logit is used to evaluate the impact of those factors on households’ ICS use. It helps to estimate the direction and strength of the relationship between various factors and types of stoves households own. Before presenting the results of MLR, it is essential to describe the key variables considered in the model:

1. Sex: The gender of the household head selected for study is labeled as male or female.
2. Marital status: The marital status of the household head is labeled as single, married or separated (widowed and divorced).
3. Education level of the head of a household is categorized in four groups: Below grade 4, Grade 4-Grade 8, Grade 9-Diploma and Degree and above.
4. Family income: This is the monthly income generated by all family members and categorized into two groups: those earning up to 6000 birr and above 6000 birr.
5. Family size: This refers to the number of family members living in one home and grouped as up to 2, 3–4, and more than 4.
6. Years lived: From the first time a household owned the land, the number of years he/she lived in the area is categorized as those who lived up to 3, 4–6, 7–9, and more than 9 years.
7. Shelter type and condition: This is the material from which the house is made and its current condition labeled as poor (made from wood and mud), good (made from wood and cement) and very good (made from steel and blockets).
8. Shelter size: This refers to the number of quarters (rooms) in a home that can be described by the number of bedrooms and labeled as 1 room, 2 rooms, 3 rooms, and more than 3 rooms.
9. Land title: This is how informal settlers’ owned land is classified as purchased land, informally owned land, and inherited land.
10. Factors affecting the choice of stoves: These factors include lowering cost of energy, saving family labor and time, availability, durability/quality, affordability, simplicity of use, safe and clean, subsidized and easy to obtain credit facilities, and stoke recognition. The stoves are labeled as open fire three-stone stoves, Mirt stoves, Lakech stoves, and electric stoves.

Table 4 presents the parametric estimates used to determine households’ ICS choice and the estimated p-values. Then, households’ choice of ICS is measured by comparing each group of stoves (Mirt stoves, Lakech stoves and electric stoves) against the reference category (i.e., the three-stone traditional stoves) along a spectrum of variables. The reference category is used as a relative measure. Then, each group of stoves is compared to the base category centered on the relevant variables considered.

Valid households considered for this analysis are 423 (94%) and the Chi-square test indicating the model with those factors considered, significantly affects the choice of ICS with \( \chi^2(54) = 388.51 \) and \( p < 0.0000 \). Although a higher value of Pseudo R2 closer to one indicates the best fit of the model, the outcomes of this study are still valid.

The analysis indicated that provided all other relevant variables in the model remain constant, relative to the traditional three-stone stove, as households’ shelter condition improves by one unit (i.e., from poor to good or from good to very good conditions), the number of households...
The choice of Lakech stoves depends on shelter type and land title held by a household. Like Mirt stoves, under ceteris paribus assumption, as the shelter condition owned by a household improves by one level, the number of Lakech users increases by 1.1119 units relative to the three-stone traditional stove users. That is, household members who lived in a relatively good shelter use more Lakech stoves than the open fire traditional three-stone stoves. However, as informal settlers’ land insecurity increases by one unit and if there is a high possibility of eviction by a single letter, the number of Lakech users decreases by 0.4505 units while those using applying the traditional three-stone stoves increases.

The choice of electrical stoves is influenced by various factors. The data show that household heads with higher levels of education who live in relatively better homes (such as those who live in good and very good shelter) and remain for longer periods in the area, are also found to be using more electrical stoves than the traditional three-stone stoves. For instance, holding all other relevant variables constant, as household heads education increase by one level, the number of electric stove users increases by 1.0173 units; as the length of time a household lived in the area increases by 1-year, electric stove users increase by 0.6742 units; and as the condition of shelter owned by residents improves by one stage, the demand for electrical stoves increases by 1.2905 units relative to the traditional three-stone users.

Household members also choose electrical stoves that lower the operating cost of energy (save family labor and time), and that are long-lasting, affordable, and simple to use. For example, under ceteris paribus assumption and relative to the three-stone stoves, as electrical stoves save operating cost and this saving increases by one unit, the demand for this stoves increases by 1.4825; as the quality of electrical stoves increases by one unit (become more durable), their demand increases by 0.7756; and as the purchase price of these stoves increases by one unit, their demand decreases by 0.7326; and as the simplicity to use electrical stoves improves by one unit, their demand increases by 0.8286.

Similarly, household heads with higher levels of education living in relatively better homes for longer periods in an area are found to be using more electrical stoves than the traditional three-stone stoves. The empirical data show that, holding all other relevant variables constant, as household heads education increase by one level, the number of electric stove users increase by 1.0173; as the condition of shelter owned by residents improves by one unit, the demand for electrical stoves increases by 1.2905; and as the length of time a household lived in an area increases by one year, electric stove users increase by 0.6742 relative to the traditional three-stone users.

### Table 4 (continued)

|                  | Coef. | Std. Err. | Z    | P > |Z|  |
|------------------|-------|-----------|------|-----|----|---|
| 3-stone stove    |       |           |      |     |    |   |
| Clean and safe   | 0.0242| 0.3177    | 0.08 | 0.939 | |
| stove            |       |           |      |     |    |   |
| Subsidized stove | -0.1756| 0.1828   | -0.96 | 0.337 | |
| Widerly known    | 0.0476| 0.1787    | 0.27 | 0.79 |    |   |
| stove            |       |           |      |     |    |   |
| _cons            | -0.7658| 1.8939   | -0.40 | 0.686 | |
| Electric stove   |       |           |      |     |    |   |
| Sex              | 0.3383| 0.4269    | 0.79 | 0.428 | |
| Marital status   | 0.5568| 0.4766    | 1.19 | 0.234 | |
| Education        | 1.0173*| 0.2694   | 3.78 | 0    |    |   |
| Family income    | 0.2463| 0.5561    | -0.44 | 0.658 | |
| Family size      | -0.2987| 0.3284   | -0.91 | 0.363 | |
| Years lived      | 0.6742*| 0.238    | 2.83 | 0.005 | |
| Shelter type     | 1.2905*| 0.4482   | 2.88 | 0.004 | |
| Shelter size     | 0.3646| 0.2768    | 1.32 | 0.188 | |
| Land title       | 0.2652| 0.2401    | 1.10 | 0.269 | |
| Stove operating  | 1.4825*| 0.2684   | 5.52 | 0.000 | |
| cost             |       |           |      |     |    |   |
| Save labor and   | 0.7222| 0.4486    | 1.61 | 0.107 | |
| time             |       |           |      |     |    |   |
| Availability of   | -0.2224| 0.2045  | -1.09 | 0.277 | |
| stove            |       |           |      |     |    |   |
| Quality of stove  | 0.7756*| 0.2235   | 3.47 | 0.001 | |
| Cost of stove    | -0.7326*| 0.294    | -2.49 | 0.013 | |
| Simple to use    | 0.8286*| 0.2988   | 2.77 | 0.006 | |
| Clean and safe   | -0.3461| 0.4797   | -0.72 | 0.471 | |
| stove            |       |           |      |     |    |   |
| Subsidized stove | -0.3315| 0.2000   | -1.66 | 0.097 | |
| Widerly known    | 0.2396| 0.2054    | 1.17 | 0.243 | |
| stove            |       |           |      |     |    |   |
| _cons            | -19.9554| 3.2376   | -6.04 | 0.000 | |

Note: *, ** and *** are statistically significant at p < 1%, p < 5% and p < 10%, respectively and the bold figures inside the table indicate the significant variables affecting households stove choice.
Source: Data developed by the author, Feb., 2022

using Mirt stoves increases by 0.7678 units; as the stove-operating cost increases by a unit, its demand decreases by 0.2942 units compared to prior periods; if its availability decreases in the market or when the level of shortage increases by a unit, its demand decreases by 0.3447 units; as the simplicity to use the stove increases by one level, households’ demand increases by 0.2853; as the households lack of awareness/recognition level increases by a unit, the demand for Mirt stoves decreases by 0.3183 units.
Household members also choose electrical stoves that are of high quality /long lasting/, affordable, and simple to use. Such stoves are found to lower the operating cost of energy and save family labor and time. For example, under ceteris paribus assumption, as the quality or durability of electrical stoves increases by one unit, the number of households using them increases by 0.7756. As the purchasing cost of the stove increases by one unit (i.e., if the price becomes more expensive), its demand decreases by 0.7326 units; and an increase in electricity tariffs by one unit leads to an increase in electrical stove usage by 1.4825 units. The latter result could signify, in addition to other benefits, that electricity is clean and more convenient to use, and the tariff is still lower than the cost of employing biomass. However, these stoves are less affordable and less subsidized than the traditional three-stone stoves.

The findings from the descriptive analysis and the MLR model yielded similar results for many of the variables considered. In both cases, the factors affecting the choice of stove vary based on the type of stove considered. However, the descriptive analysis shows the positive contribution of shelter size to own ICS while this is not a significant factor in the logistic regression. This is because the descriptive analysis treated the factors affecting the choice of stoves independently while the MLR estimated the interactive effect of all variables on households’ energy-efficient stove choice.

**Conclusions and implications**

**Conclusions**
ICS burn fuels cleanly, save time, cost, workload of family members involved in cooking activities, and contribute to the sustainable usage of scarce resources. The choice of these stoves and appliances, however, depend on households’ socio-economic backgrounds and availability as well as affordability of alternative energy sources.

The findings of both MLR and descriptive statistics showed that sex, family size and family income have no relationship with the usage of energy-efficient stoves. However, education level of the household head, the number of years lived in the area, shelter type and size owned, energy price /operating cost/, availability, affordability and quality of the stove have significant influence on ICS usage in informal settlements. These technologies help to meet ever-increasing energy needs of households and save expenditures for energy while protecting the environment.

At present, due to a shortage of fuel wood and lack of access to reliable electricity supply in Ethiopia, households using ICS are growing significantly in number (8% before 10 years to 51% in the last 5 years).

**Implications**
Since the prices of ICS are rapidly increasing, arranging loan facilities, flexible payment systems, subsidies and incentives to households are critical policy issues. On the other hand, such schemes should discourage the use of open fire traditional stoves and the consumption of high polluting energy sources through requiring payments in the form of taxes and penalties. Solar energy should also be used beyond lighting and charging of batteries. Integrating households’ socio-economic backgrounds with their energy sources promoting the usage of energy-efficient cooking stoves could be seen as a major policy issue in informal settlements.

**Future research directions**
This study analyzed the factors that determine the adoption of ICS in informal settlements from the perspectives of households using cross-sectional data. Future research, however, could focus on ICS suppliers’ problems, government policies and energy consumption behavior of household members by using panel data and optimizing the needs of different stakeholders.

**Abbreviations**
CFL: Compact fluorescent lamps; EET: Energy-efficient technologies; ICS: Improved cook stoves; LED: Light-emitting diodes; LPG: Liquefied petroleum gas; MTF: Multi-tier framework; PV: Photovoltaic; SDGs: Sustainable development goals.
accepted, it will not be published elsewhere in the same form, in English or in any other language without the written consent of the copyright-holder.

Consent for publication
Not applicable.

Competing interests
The authors declare that there are no financial interests or personal relationships that could have influenced the findings of this research.

Author details
1 Center for Environment and Development, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia. 2 Geography and Development Studies, Addis Ababa University, Addis Ababa, Ethiopia.

Received: 26 August 2021 Accepted: 12 October 2022
Published online: 07 November 2022

References
1. Reyna JL, Chester MV (2017) Energy efficiency to reduce residential electricity and natural gas use under climate change: Nat Commun 8(14916).
2. Bhattacharjee S, Reichard G (2011) Socio-economic factors affecting individual household energy consumption: a systematic review, Proceedings of the ASME 2011 5th International Conference on Energy Sustainability. Washington, DC. https://www.researchgate.net/publication/267646836
3. Chagunda MF, Kamunda C, Mlatho J, Miekka C, Palamuleni L (2017) Performance assessment of an improved cook stove (Esperanza) in a typical domestic setting: implications for energy saving. 7(19)
4. Sohagab K, Begum RA, Abdullaha SM, Jaafar M (2015) Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. Energy 90(2):1497–1507
5. Parka C, Xingb R, Hanakob T, Kanamoryb Y, Musiub T (2017) Impact of energy efficient technologies on residential CO2 emissions: a comparison of Korea and China. Energy Procedia 111:689–698
6. Flores WC, Benjamin B, Pino HH, Al-Sumaiti A, Rivera S (2020) A national strategy proposal for improved cooking stove adoption in Honduras: energy consumption and cost-benefit analysis. Energies. https://doi.org/10.3390/en13040921
7. Mfundai KB, Commeh MK (2019) Clean cookstove technology use for energy efficiency in the school system. J Nat Resour Dev. https://doi.org/10.5027/jnrd.v9i0.04,9,34-41
8. Saneeepur S, Saneeepur H, Kargari A, Habibi MH (2014) Renewable energies: climate-change mitigation and international climate policy. Int J Sustain Energy 33(1):203–212
9. Olugbire O et al (2016) Determinants of household cooking energy choice in Oyo State, Nigeria. RUAS 4(52):28–36. https://doi.org/10.18551/ruas.2016-04.04
10. Cai W, Grant H, Pandey M (2018) Vintage capital, technology adoption and electricity demand-side management. Energy J 39(2)
11. Kamen DM (2011) Household cookstoves, environment, health, and climate change: a new look at an old problem. World Bank EIA. (2019). https://www.eia.gov/cleanenergyplanned/use-of-energy/efficiency-and-conservation.php
12. CCA. https://cleancooking.org/. Clean Cooking Alliance (CCA). [Online] April 30, 2022
13. Shellendenber, M, Nordhaus T (2014) The problem with energy efficiency. The New York Times, New York
14. Feldmann L, Otremba D (2015) Efficient cookstoves & cooking energy efficiency for a healthier living. Frakfurt, Germany: Internationale Zusammenarbeit (GIZ).
15. Herring H, Roy R (2007) Technological innovation, energy efficient design and the rebound effect. Technovation 27(4):194–203
16. Illegbesana AP, Rampedia IT, Annegam HJ (2016) Nigerian households’ cooking energy use, determinants of choice, and some implications for human health and environmental sustainability. Habitat Int. https://doi.org/10.1016/j.habitatint.2016.02.001,55,17-24
17. Pedam G et al (2018) Ethiopia-Beyond connections: energy access diagnostic report based on the multi-tire framework. World Bank Group, Washington DC
18. Padam G et al (2018) Ethiopia-Beyond connections: energy access diagnostic report based on the multi-tire framework. World Bank Group, Washington DC
19. Yonas A, Abebe B, Köhlin G, Alemu M (2016) Modeling household cooking fuel choice: a panel multinomial logit approach. Energy Econ 59:129–137
20. Medina A, Câmara Á, Monrobel J-R (2016) Measuring the socioeconomic and environmental effects of energy efficiency investments for a more sustainable Spanish economy. Sustainability 8:1–21
21. Amoah ST (2019) Determinants of household’s choice of cooking energy in a global south city. Energy Build 196:103–111
22. Triannia A, Cagnob E, Worrell E (2013) Innovation and adoption of energy efficient technologies: an exploratory analysis of Italian primary metal manufacturing SMEs. Energy Policy 61:430–440
23. Grueneich DM (2015) The next level of energy efficiency: the five challenges ahead. Electr J 28:44–56
24. Barnes DF, Golumbeanu R, Diao I (2016) Beyond electricity access: output-based aid and rural electrification in Ethiopia. World Bank, Washington, DC
25. Zeng Y, Dong P, Shi Y, Li Y (2018) On the disruptive innovation strategy of renewable energy technology diffusion: an agent-based model. Energies 11:1–21
26. Kanyamuka JS (2017) Adoption of integrated soil fertility management technologies and its effect on maize productivity: a case of the legume bets project in Mkanakhoti extension planning area of Kasungu District in Central Malawi, Thesis in Agril. & applied economics. Lilongwe University of Agriculture and Natural Resources.
27. Bayera P et al (2020) The need for impact evaluation in electricity access research, Energy Policy 137
28. Nepal M, Nepal A, Grimsrud K (2010) Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. Environ Dev Econ 16:1–23
29. Mogabak A, Dwivedi P, Bailis R, Hildemann L, Miller G (2012) Low demand for nontraditional cookstove technologies. Proc Natl Acad Sci 109:10815–10820
30. World Vision (2016) Easing Women’s life: The energy efficient cook stove. Addis Ababa
31. MWEIE (2017) The Ethiopian power sector: a renewable future, Berlin Energy Transition Dialogue. Berlin: Ministry of Water, Irrigation and Electricity
32. energypedia (2019) Ethiopia Energy Situation
33. Tiruye GA, Besha AT, Mekonnen YS, Bentì NE (2021) Opportunities and challenges of renewable energy production in Ethiopia. Sustainability. https://doi.org/10.3390/su131810381
34. Sheng P, He Y, Guo X (2017) The impact of urbanization on energy consumption and efficiency. Energy Environ 28:673–686
35. Abebe DB, Koch SF (2013) Clean fuel-saving technology adoption in urban Ethiopia. Energy Econ 36:605–613
36. World Vision (2013) Fuel-efficient cook stoves: a triple win for child health, development and environment
37. Mondal MA, Bryan E, Ringle C, Mekonnen R, Rosegrant M (2018) Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions. Energies 149:161–172
38. Ekouevi K, Freeman KK, Soni R (2014) Liveiwire; understanding the differences between cook stoves
39. Chen B (2016) Energy, ecology and environment: a nexus perspective. Joint Center on Global Change and Earth System Science of the University of Maryland and Beijing Normal University, 1: 1–2
40. Gebreegaabhiher Z et al (2012) Urban energy transition and technology adoption: the case of Tigrai, northern Ethiopia. Energy Econ 34:410–418
41. Howell J (2011) Environmental policy review: rural electrification & output-based aid and rural electrification in Ethiopia. World Bank, Washington, DC
42. WB (2020) Energy Situation, Ethiopia Group. Addis Ababa: energypedia.info
43. Zenebe G et al (2018) Fuel savings, cooking time and user satisfaction with improved biomass cook stoves: Evidence from controlled cooking tests in Ethiopia
44. Bekere YB, Megegensa GR (2020) Role of biogas technology adoption in forest conservations: evidence from Ethiopia. J Degraded Mining Lands Manag 7:2502–2458
45. Gedadda T, Melka Y, Sime G (2021) Determinants of Biogas technology adoption in rural households of Aleta Wondo District, Sidama Zone, Southern Ethiopia
46. Woubishet D (2008) Fuel efficient technology adoption in Ethiopia: a Case in selected Kebeles from "Adea" Wereda. XVI
47. Ouedraogo NS (2017) Africa energy future: alternative scenarios and their implications for sustainable development strategies. Energy Policy 106:457–471. https://doi.org/10.1016/j.enpol.2017.03.021,106,457-471
48. Shove E (2018) What is wrong with energy efficiency? Build Res Inf 46(7)
49. Dawit DG (2020) Determinants of household use of energy-efficient and renewable energy technologies in rural Ethiopia. Technol Soc 61:1–8
50. Wassie YT, Adaramola MS (2021) Socio-economic and environmental impacts of rural electrification with Solar Photovoltaic systems: evidence from southern Ethiopia. Energy Sustain Dev 60:52–66
51. Hailu AD, Kumsa DK (2020) Ethiopia renewable energy potentials and current state, 9(1)
52. Boke MT, Moges SA, Dejen ZA (2022) Optimizing renewable-based energy supply options for power generation in Ethiopia. PLoS ONE. https://doi.org/10.1371/journal.pone.0262595

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.