Scientific Research Publishing

Technology and Investment, 2026, 17(3), 295-307
https://www.scirp.org/journal/ti
ISSN Online: 2150-4067
ISSN Print: 2150-4059

Factors Influencing the Use of Improved Charcoal Kilns by Charcoal Producers in Kilindi District, Tanzania

Peter Fitwangile, Felister Mombo*

Department of Forest and Environmental Economics, College of Forestry, Sokoine University of Agriculture, Morogoro, Tanzania
Email: *fmombo@yahoo.com, *fmombo@sua.ac.tz

How to cite this paper: Fitwangile, P., & Mombo, F. (2026). Factors Influencing the Use of Improved Charcoal Kilns by Charcoal Producers in Kilindi District, Tanzania. *Technology and Investment, 17,* 295-307.
https://doi.org/10.4236/ti.2026.173016

Received: January 19, 2026
Accepted: August 28, 2026
Published: August 31, 2026

Abstract

Despite the increasing adoption of modern improved charcoal kilns in many developing countries, reliance on inefficient and unsustainable traditional kilns remains. This paper examines the factors influencing the adoption of improved charcoal kilns by charcoal producers in Kilindi District, Tanzania. We used a questionnaire to collect data from 200 respondents and conducted two focus group discussions. The logistic regression results reveal that the age of the respondents, participation in charcoal social networks, income level, the attitude of charcoal producers, and training on improved kilns increased the probability of charcoal producers using improved kilns over traditional kilns, where marital status reduces the possibility of a producer using improved kilns. The study concludes that a large number of charcoal producers in the study area still use traditional kilns despite the benefits of using improved kilns. In order to promote sustainable environmental protection and promote positive social and economic outcomes, it is important that charcoal producers adopt a sustainable, environmentally friendly improved kilns.

Keywords

Charcoal, Kilns, Conservation

1. Introduction

Charcoal production is one of the major economic activities in many developing countries due to its economic importance, especially in regions where access to modern energy sources is limited. This is because, in seasons of poor crop and livestock production, charcoal production provides regular household income and seasonal income that provides a safety net against economic crises and helps families escape poverty (Brobbey et al., 2019). Studies show that charcoal is the primary fuel for 1.3 billion people worldwide and 195 million people in sub-Saharan Africa (Rose et al., 2022). In Tanzania, charcoal is one of the main sources of energy in the country (World Bank, 2009). In the country, about 90% of the country's energy needs are met only by using charcoal and wood.

Charcoal consumption is about 2650 tons per day, which equates to one million tons per year or about 1 cubic meters of round wood per person per year. The value of the entire charcoal sector in the country is approximately $1 billion (URT, 2014; TFCG & MJUMITA, 2022). The amount of wood used for charcoal production is about 30 million cubic meters. For charcoal production, about 160,000 kilns are used annually, of which 438 are used per day (Zulu & Richardson, 2012). About 53 million tons of charcoal are produced worldwide, and Africa's contribution is about 63% (Dam, 2017). The use of charcoal is widespread due to its strength, durability, popularity and cost compared to other fuels such as kerosene and fuel oil (Kappel & Ishengoma, 2006). Demand and production of charcoal in sub-Saharan Africa is expected to double by 2030, and more than 700 million Africans depend on it as a source of income and energy (Kappel & Ishengoma, 2006; Rose et al., 2022).

Studies show that traditional charcoal production is linked to environmental degradation, deforestation and climate change (Chidumayo & Gumbo, 2013; UNEP, 2002; FAO, 2017). Despite its inefficiency in charcoal production, still it is a widespread form of charcoal production. Traditional charcoal production methods are often inefficient, with low conversion rates from wood to charcoal (Dam, 2017; Bekele & Kemal, 2022; Charvet et al., 2022; Mensah et al., 2022) leads to more deforestation, which makes deforestation worse. Traditional charcoal production is linked to environmental degradation, deforestation, and climate change (Brobbey et al., 2019; Chidumayo & Gumbo, 2013). In addition, these charcoal-producing areas are not properly managed, resulting in land degradation (Bekele & Kemal, 2022). Inefficient traditional charcoal kilns force producers to use more trees to produce the same unit of output because of the high losses in the process. As a result, production using inefficient kilns not only leads to wood depletion, but charcoal producers also lose a significant part of their production, which can translate into a higher profit if the loss is controlled.

The traditional charcoal production also involves incomplete combustion, resulting in the release of large amounts of carbon dioxide and other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) (Tassie et al., 2021; Temmerman, 2016; Usui et al., 2018). These emissions are a major contributor to global warming and climate change. In tropical countries, it is estimated that traditional charcoal production will emit about 71.2 million tons of carbon dioxide and 1.3 million tons of methane, which accounts for 7% of deforestation (Iiyama et al., 2014; Chidumayo & Gumbo, 2013). Previous studies (e.g. Temmerman, 2016; Neufeldt et al., 2015; Fitwangile, 2017) reported that the use of charcoal improves the efficiency of the fire. Despite this proven fact, most of charcoal producers in Tanzania still use traditional kilns in charcoal making with conversion efficiency of less than 20% which lose about 60% to 80% of the woods energy (BTG, 2010; Neufeld et al., 2015; Morgan & Samwel, 2016, 2015; TFCG & MJUMITA, 2022). Therefore, the overall aim of this paper is thus to examine the factors influencing charcoal producer to use improved kilns in charcoal production. The findings will depict an understanding of what in first influences the decision of a producer on choosing kiln technology. The findings will be useful to policy makers on designing policies which will be suitable to encourage many producers to use improved kilns technology for livelihood enhancement, poverty reduction, and environmental conservation.

2. Methodology

2.1. The Study Area

The study was conducted in Kilindi district of Tanga region. The district is situated between 5.015˚ South and 6.005˚ South and longitude 37.05˚ East and 38.05˚ East. It has a total area of approximately 6443.52 km^2 with 21 wards and 102 villages. The district has a population of 236,833 with density of 37 per km^2 (National Census, 2022) The altitude of this area ranges from 1000 - 2400 m above the sea level. As **Figure 1** shows, in the east the district is boarded by Handeni district, to the south-east by Bagamoyo, to the west by Mvomero and Gairo, to

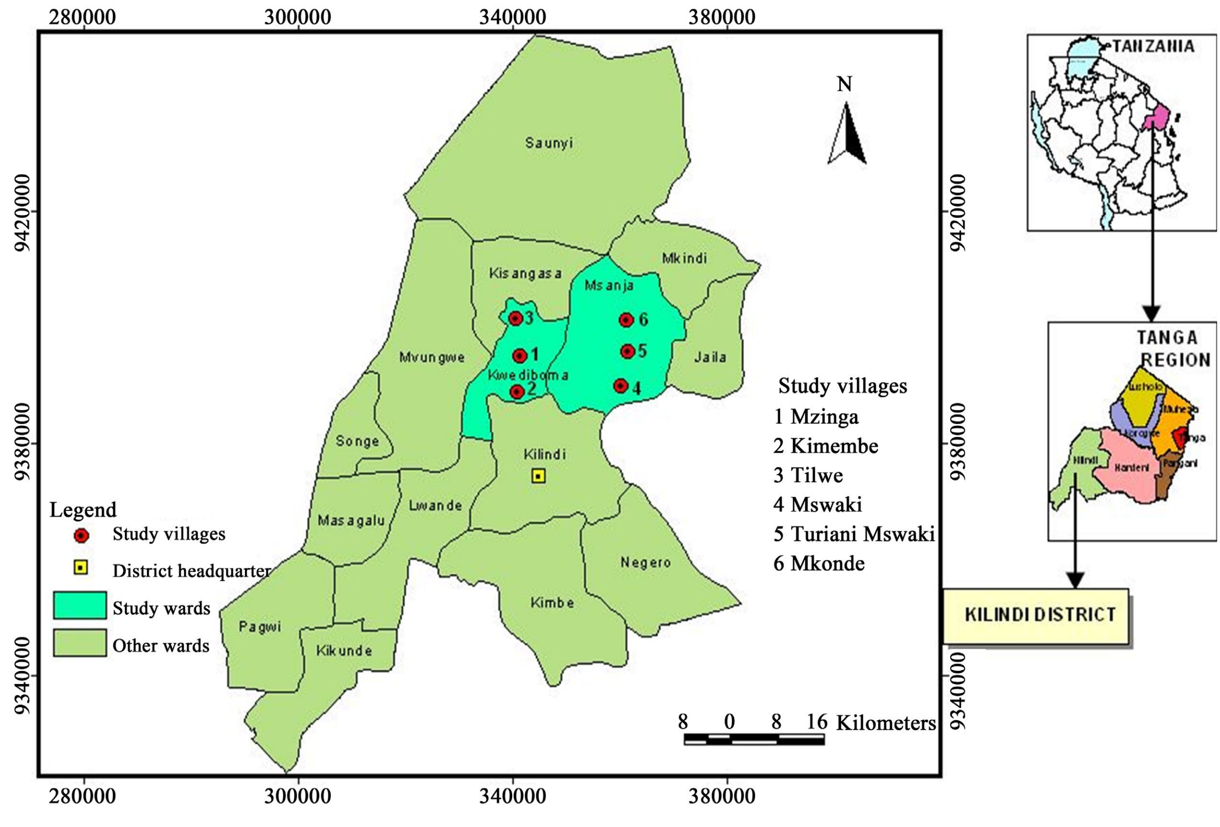

Figure 1. A map of the study area. (Source: Fitwangile et al., 2023).

the north Kilindi is boarded by Simanjiro and Kiteto to the north-west. The climate range from hot and humid in dry plains to temperate in the mountains. The annual rainfall ranges between 500 - 800 mm, the long rains are from February to May; and short rains from August to November (Hamilton, 1989). The temperatures of the area range from 21˚C to 24˚C. Kilindi District is rich in indigenous and exotic tree species. It is characterized and dominated by woody plants, herbs, grasses and Miombo woodland respectively.

2.2. Sample Size and Sampling Procedures

A cross-sectional design was employed for this study due to its suitability for collecting data at a single point in time from a large population, making it both economical and flexible. The sampling frame consisted of charcoal producers in Kilindi District. Using simple random sampling, two wards; Msanja and Kwediboma, were selected from the list of 21 wards. From each ward, one village was then purposively chosen based on charcoal production activities: Mswaki (Msanja) and Kimembe (Kwediboma). This purposive step ensured that the study focused on communities actively engaged in charcoal production, but it also introduces a potential risk of selection bias, as these villages may not fully represent the broader district. For instance, they may have benefited from past NGO interventions or possess unique market access, which could influence adoption patterns. To mitigate bias at the respondent level, random sampling was applied to select 200 charcoal producers (both users of improved and traditional kilns) for the questionnaire survey. In addition, two focus group discussions (one in each village) were conducted to enrich the data and provide qualitative insights into the factors influencing kiln adoption.

2.3. Description of Improved Kiln Technology

In Kilindi District, charcoal producers have adopted two main types of improved kilns: brick kilns and Casamance-type kilns. These technologies differ significantly from the traditional earth mound kilns that dominate rural production.

Brick kilns are constructed using bricks or reinforced earth structures and are fitted with chimneys or vents to regulate airflow. Their design allows for more complete combustion of wood, resulting in conversion efficiencies of approximately 30% - 40%, compared to less than 20% for traditional kilns. Brick kilns are durable and reusable, offering producers a longer operational lifespan and higher yields of charcoal per unit of wood consumed (Temmerman, 2016).

Casamance kilns are modified earth mound kilns that incorporate a chimney to improve combustion efficiency. They are less costly to construct than brick kilns and therefore more accessible to small-scale producers. Their efficiency ranges between 25% - 30%, which is still a notable improvement over traditional kiln. Casamance kilns are often favored by producers who lack the resources to invest in brick kilns but still seek to reduce wood wastage and increase output (Stassen, 2015).

By contrast, traditional earth mound kilns are built by covering stacked wood with soil. They are inexpensive and easy to construct but highly inefficient, with conversion efficiencies below 20%. These kilns result in significant losses of wood energy and contribute heavily to deforestation and greenhouse gas emissions (BTG, 2010; Fitwangile et al., 2023).

2.4. Data Analysis

Characterization of charcoal production kilns in the study area

Descriptive statistics were used for identification of different types of kilns used and other properties of those kilns such as shape and size. This objective also differentiated the number of charcoal producers who are using traditional kilns to improved ones. In addition, socio - economic characteristics of charcoal producers were presented and compared between charcoal producers who used improved kilns and traditional kilns. The comparison was made using chi-square test to see if there is any statistical difference in a given socio-economic characteristic and use of improved or traditional kilns.

The factors influencing adoption of improved kilns

The factors influencing the charcoal producer to adopt the use of improved kilns was analysed by using logistic regression. According to Wale and Yallew (2007) modelling producer's decision on whether or not to adopt a technology constitute a discrete decision of whether or not to take up the technology. In number of adopting models assumes that producers are faced with choice of two alternatives whereby these choices depend on identifiable characteristics of technology (Kaguongo et al., 2010). According to Kaguongo et al. (2010) modelling adoption following the random utility theory the decision of producers on whether or not to adopt the technology is guided by a utility maximizing objective which states that; "T*echnology 2* (k_2) *is preferred to technology 1* (k_1) *only if the utility derived from new technology* (k_2) *is greater than the utility derived from old and existing technology* (k_1)". The utility function ranking of i^{th} producer's' preference for technology is presented as shown in Equation (1) below.

$$U\left(C_{ki}; A_{ki}\right) \tag{1}$$

where, C = Vector of production and producer specific attributes of the adopter, A = Vector of the attributes associate with the technology.

Technology adoption is defined by k with k_2 for new technology and k_1 for old technology. This implies the utility derived from adopting new technology depend on C and A. The variables C_{ki} and A_{ki} are not observable but a linear relationship is postulated between utility U derived from the i^{th} technology, a vector of observable production and producer characteristics X_i and a random disturbance term μ_k with zero mean as shown in Equation (3).

$$U_{ki} = \alpha_k X_{ki} + \mu_k \tag{2}$$

where, k = 1 (traditional kiln), 2 (improved kiln) and $i = 1, \cdots, n$. U_{ki} are random and therefore, the i^{th} producer will select the alternative kiln (k_2) if $U_{2i} > U_{1i}$ or the latent random variable is as shown in Equation (4)

$$y^* = U_{2i} - U_{1i} > 0 \tag{3}$$

A qualitative variable Y_i can represent the i^{th} producer's decision where $Y_i = 1$ if $U_{k2} > U_{k1}$ and new technology k_2 is adopted adopting k_1 and $Y_i = 0$ otherwise. The margin effect of a variable X_j on the probability of adopting new technology can be computed by differentiating P_i with respect to X_j as shown in Equation (5).

$$\frac{\partial P_i}{\partial X_{ij}} = f\left(X_i \beta\right) \cdot \beta_j \tag{4}$$

where, $f(.)$ is the margin probability density function of γ_j and $j = 1, 2, \cdots, J$ is the number of explanatory variables. The general form of the univariate dichotomous choice model is expressed as shown in Equation (5).

$$P_i = P_i\left(Y_i = 1\right) = D\left(X_i, \theta\right) \tag{5}$$

where, $i = a, 2, \cdots, n$

Equation (5) states the probability that the i^{th} producer will adopt a specific technology is a function of the vector of explanatory variables X_i and unknown parameters vector θ. To specify D Logit model will be used.

This study will use the logit model to evaluate factors associated with charcoal producer's decision to use or not improved charcoal kilns. In the logit model, the probability of an individual farmer adopting improved kiln given a set of socio-economic and physical characteristics of (*X*) is given as shown in Equation (6).

$$P\left(X\right) = \frac{\exp\left(\beta_0 + X_i \beta_i + \mu\right)}{1 + \exp\left(\beta_0 + X_i \beta_i + \mu\right)} \tag{6}$$

Similalry, the probability of not adopting the new kiln k_2 (continuing with traditional kilns k_2) is as shown in Equation (8) below.

$$P\left(X\right) = 1 - P\left(X\right) = 1 - \frac{\exp\left(\beta_0 + X_i \beta_i + \mu\right)}{1 + \exp\left(\beta_0 + X_i \beta_i + \mu\right)} = \frac{1}{1 + \exp\left(-\left(\beta_0 + X_i \beta_i + \mu\right)\right)} \tag{7}$$

In this model the parameters are linear with normally distributed disturbance term.

Now dividing Equation (6) by Equation (7), gives the odds ratio in favour of adopting improved kiln by a charcoal producer as shown in Equation (8) below.

$$\frac{P\left(X\right)}{1 - P\left(X\right)} = \frac{\dfrac{\exp\left(\beta_0 + X_i \beta_i + \mu\right)}{1 + \exp\left(\beta_0 + X_i \beta_i + \mu\right)}}{\dfrac{1}{1 + \exp\left(-\left(\beta_0 + X_i \beta_i + \mu\right)\right)}} = \exp\left(\beta_0 + X_i \beta_i + \mu\right) \tag{8}$$

By introducing natural logarithm in Equation (8) results into Equation (9) as shown below.

$$L = \ln\left(\frac{P\left(X\right)}{1 - P\left(X\right)}\right) = \beta_0 + X_i \beta_i + \mu \tag{9}$$

Specific to this study Equation (9) can be extended into Equation (10) as shown below.

$$L = \beta_0 + X_1\beta_1 + X_2\beta_2 + X_3\beta_3 + X_4\beta_4 + X_5\beta_5 + X_6\beta_6 + X_7\beta_7 + X_8\beta_8 + X_9\beta_9 + \mu \quad (10)$$

where, L = Dependent variable; X_1 = Age; X_2 = Sex; X_3 = Education; X_4 = Experience; X_5 = Income level; X_6 = Charcoal producer received training; X_7 = Perceived usefulness improved kilns; X_8 = Social networks; X_9 = Marital status and μ = Error term.

3. Results and Discussion

3.1. Socio-Economic Characteristics of Charcoal Producers

Table 1 shows the characteristics of charcoal producers classified according to

Table 1. Characteristics of charcoal producers by type of kiln used (in percentage).

Variables	Traditional kilns	Improved kilns	*N*	χ^2-test
Age				0.054**
Less than 35 years	30.5	15	45.5	
35 years and above	30	24.5	54.5	
Sex				0.068*
Female	22	10	32	
Male	38.5	29.5	68	
Marital status				0.154
Single	9	8.5	17.5	
Married	51.5	31	82.5	
Education level				0.988
No school	6.5	4.5	11	
Primary	48	31	79	
Secondary and above	6	4	10	
Experience in charcoal production				0.050**
Less than a year	5	2	7	
1 to 5 years	46	23.5	69.5	
Above 5 years	9.5	14	23.5	
Training				0.000***
Charcoal producer did not receive training	37	4.5	41.5	
Charcoal producer received training	23.5	35	58.5	
Total	60.5	39.5	100	

the type of kiln used to produce charcoal as summarized in the Table. As can be seen, 60.5% of all charcoal producers use traditional kilns while 39.5% use improved charcoal. Age seems to significantly influence the decision of the type of kilns to be used, the significancy is clear when it's on choice to use improved kilns unlike when it is for traditional kiln as out of 39.5% of charcoal producers who use improved kilns, less than 50% of these are aged < 35 and 62% of the improved kilns users are aged ≥ 35 years. A chi-square test of 0.054 shows the existence of a significant difference between the age of charcoal producer and the type of kiln used to produce charcoal as it was found in Tazebew, (2023) how the type of kiln influenced the efficiency of charcoal production.

Regarding the gender of charcoal producers, the difference is also visible when a choice is on improved kiln since out of 39.5% of the charcoal producers who use improved kilns, only 10% are women and 90.5% are men. A chi-square test of 0.068 confirms the existence of a significant difference between the gender of charcoal producers and the type of kiln used to produce charcoal.

Regarding experience in charcoal production, among the 60.5% of producers who use traditional kilns, only less than 1% have less than one year of experience, whereas about 99% of all traditional kilns users have about 5 and more years of experience. A chi-square test value of 0.050 indicates the existence of a significant difference between charcoal producers' experiences in charcoal production and the type of kiln used to produce charcoal. For charcoal production training, more than 60% of producers using traditional kilns, not receive charcoal production training whereas more than 90% of producers using improved kilns, received training in charcoal production. A chi-square test of 0.000 shows that there is a significant difference between training on charcoal production and the type of kiln used to produce charcoal.

Regarding marital status, more than 99% of producers who use either traditional or improved kilns, are married implying there is insignificant difference when it comes to the choice of kilns to the married in each of the types. On the level of education, more than 70% of producers whose choice is on improved kilns are educated at the level of at least primary school however the education doesn't matter on traditional choice of kilns as it does for the received trainings on charcoaling.

3.2. Factors Influencing the Use of Improved Charcoal Kilns by Charcoal Producers

This section analyses the factors influencing the use of the improved kiln by a charcoal producer in the study area. Logistic regression was used and results are presented as shown on **Table 2** below. In model summary below number of observations used were 200 producers. The p-value of 0.000 of prob > chi^2 implies at least one of the regression coefficients in the model is not equal to zero. The value of Pseudo R^2 of 0.393 implies the model has a strong goodness of fit because from the rule of thumb logistic model with strong goodness of fit have value of Pseudo R^2 ranging between 0.2 and 0.4.

Table 2. Factors influencing the use of improved charcoal kiln.

Variables	Odds ratio	Coefficient	P-value	
Age in years	4.4605	1.4953	0.001	***
Sex (1 = Male; 0 = Female)	0.9334	−0.0689	0.880	
Marital Status (1 = Married; 0 = Not married)	0.1998	−1.6106	0.005	***
Education level (1 = At least primary school; 0 = No school)	0.4552	−0.7871	0.200	
Experience in charcoal production in years	1.0981	0.0936	0.124	
Membership to charcoal social networks (1 = Yes; 0 = No)	11.4621	2.4390	0.002	***
Income level in Tanzanian shillings	1.0000	1.8e−07	0.039	**
Perception very useful (1 = Yes; 0 = No)	19.2018	2.9550	0.011	***
Producer had training (1 = Yes; 0 = No)	8.9580	2.1926	0.002	***
Number of observations			200	
Prob > chi^2			0.000	
Pseudo R^2			0.393	

In the regression six out of nine variables hypothesized to influence the use of improved kilns over traditional kiln were found to be significant. The coefficient of age has a positive sign indicating positive relationship between age and use of improved kilns; for the age variable a unit increase in age of producer by one year, the odds of producers using improved kilns increase by 4.46 given other factors constant. This implies as producer age increases the chances of using improved kilns increases by 4.46 times. According to Okaye et al. (2008) producer's age is likely to enhance good decision making through accumulated wisdom from the life experiences.

The coefficient of marital status has a negative sign indicating negative relation between marriages and using improved kilns, for a married producer the odds of using improved kiln are 0.1998 less than producers who are not married. This implies that in the study area producers who are not married are more likely to use improved kilns comparing to married producers.

The coefficient of membership to charcoal social networks has a positive sign as expected. For a charcoal producer who is a member in charcoal production social network the odds of using improved kilns are 11.46 times larger than those producers who are not members. According to Talukder (2012) individual adoption of improved technology used to be influenced by social pressure especially individuals whose belief and opinions are important including peer and people in social networks. This was also reflected in the focus group discussions as the respondent in one of the villages stated that "I *was not sure about that new kiln. But when I saw the village chairman using it, I said, 'Eh, if the leader is using it, then it must be good.' That is when I also started using the improved kiln"* Therefore, producers who are in charcoal producers' social networks are likely to use improved kilns compare to those who are not.

The coefficient of income has a positive sign as expected. However, the value of coefficient is a very small number, an increase in income of a charcoal producer, had negligible effect on the odds of producer using improved kilns. This implies that in the study area, factors other than income have influence on producer choice of using improved kilns. Aligning with the study by Fitwangile et al. (2023) which stated that income increase is not a decisive factor in adoption on improved kilns, instead the focus should be on training and awareness campaigns.

The coefficient of producer having training has a positive sign as expected. For a charcoal producer who had a training the odds of using improved kilns are 8.958 times larger than those producers who had no training. According to Abdoulaye et al. (2014) training increases producers' awareness on better production practices including the usage of new technologies. For instance, charcoal producer training on sustainable charcoal production by experts is likely to impact knowledge to producers on advantage of using improved charcoal production and therefore increases the likelihood of producers using improved technologies.

The coefficients of producers' perception have a positive sign. Producers who considered using improved kilns as very useful had higher odds of adoption compared to those who considered otherwise. For charcoal producers with the perception that improved kilns are useful, the odds of adoption are 19.2 times higher than those who perceived otherwise. In a way similar to social networks, according to Talukder (2012), perception towards technology depends on experience from peers, trusted individuals, and personal use. The perception building will influence whether or not a producer is likely to use improved kilns. As one focus group participant explained: *"Before, I thought the new kiln was just government talk. But when I saw it giving more charcoal with less wood, I said, 'This one is truly useful.' That is when I decided to try it myself.*" Another villager added: *"During the training, I saw with my own eyes how the kiln reduced smoke and saved trees. That changed my mind completely."* Similarly, a participant emphasized peer influence: *"When my neighbor showed me his bags of charcoal from the improved kiln, I believed it was useful. Without seeing that, I would not have tried."*

4. Conclusion and Recommendations

The findings from the study reveal that age, membership to charcoal social networks, income level, training and perception increases the likelihood of a producer to choose improved kiln while marital status decreases the likelihood of a producer using improved kilns in charcoal processing. Amongst all the mentioned factors training for charcoaling and social networking were found to have a very significant value and a positive coefficient implying are very important factors to be considered when it comes to the choices of which type of kilns is to be used to process charcoal by the family so specifically married one. However, it is important to note that formal education has no influence in the choice of the type of the kiln to be used by charcoal producers. This is a very important observation so specifically to the policy makers, conservators and other stakeholders. The note is important because these would want to increase the adoption rate of the improved kilns to reduce deforestation caused through the use of poor technology for this case traditional kilns that have low capacity for carbonization and also efficient use of the materials for charcoal production. To attain this important objective therefore, charcoal producers should be encouraged to form charcoal production social networks which will help to communicate and sharing various knowledge regarding charcoal production since social networks has shown to have significant effect on the decision of producer choice of improved kilns. Also, local governments through District Forest officers as the direct people who have mandate over implementing a Forest Policy in the local government within the local councils, should conduct trainings on advantages of using of improved charcoal kilns among charcoal producers in the study area since it has shown a positive influence towards the choice of type of kilns to be used by a household. Those charcoal producers who received training had a greater possibility of choosing the improved kilns other than those who choose traditional kilns. The officers should also facilitate the locals in forming social networks as this also have proved to influence the household decision on the type of kiln to be used. The social network is now possible through use of smart phones, it takes less time and can be easily accessed from any location when there is a network nearby. Charcoal producers receive income in cash so it will be easy if their business strategy can be enhanced through the use of mobile phones.

Academic institutions and other stakeholder organisations should conduct further research in the study area to find out why married charcoal producers have shown to be less likely to use improved charcoal kiln in the study area as compared to those who are not married; this study could not ascertain what are the reasons behind this observation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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