The Dynamics of Household Labor allocation to Biogas production, Farm and Non-farm activities in Central Uganda

Abstract

Biogas is a sustainable energy that contributes to improved health and provides socio-economic benefits. However, biogas production has an impact on an essential household resource; labor. Therefore, households need to efficiently allocate labor to activities on the farm, off-farm and for biogas production. There is little empirical evidence on the factors influencing labor allocation within farm households, thus limiting biogas technology promoters from creating a favorable environment for uptake. This study fills this gap. Data were obtained from households with biogas digesters in central Uganda through a snow-balling sampling technique. A household model was used, and labor share equations were estimated by a Seemingly Unrelated Regression model. Own activity labor returns showed a positive relationship to the respective labor share, but cross-labor returns were negatively related. Female-headed households were more likely to allocate labor to biogas activities. Distance to water source had a negative impact on labor allocation to biogas activities, while the number of cattle owned by the household had a positive impact. Age of the household head and household size had a positive impact on labor allocation to non-farm activities. Household labor should be critically analyzed before investing in biogas digesters to increase the success of the technology.

Keywords: Biogas technology, labor, resources, up-take

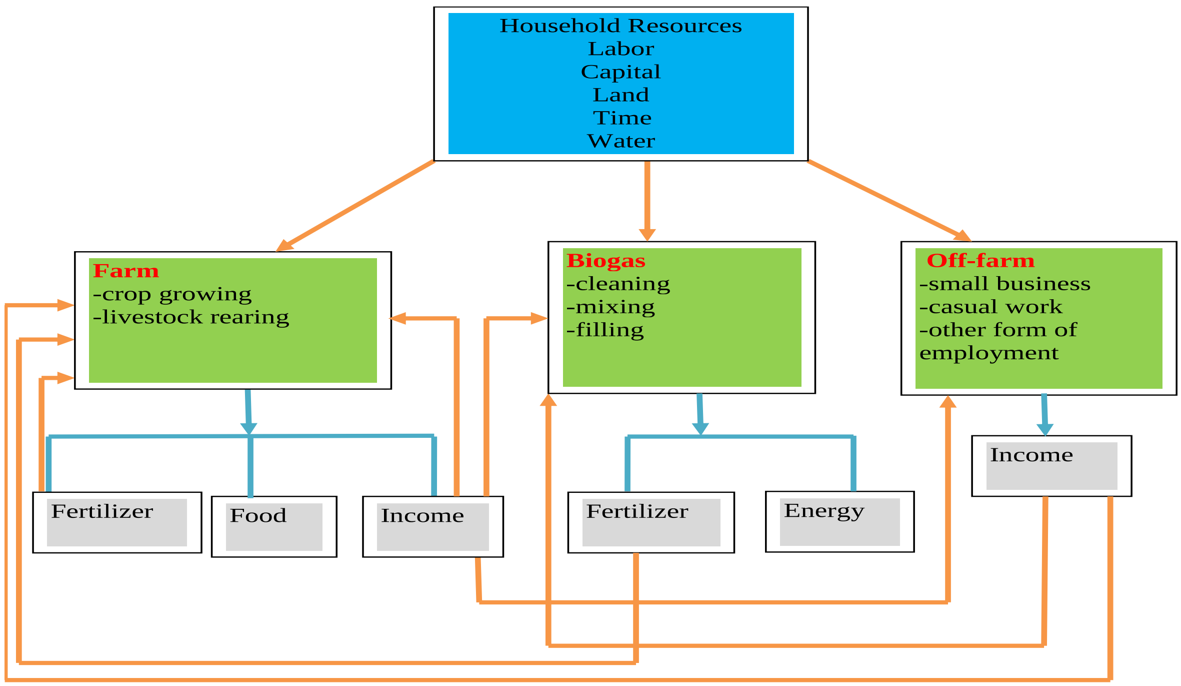
1. Introduction

Over 80% of African households depend on traditional biomass fuel to satisfy their daily cooking needs (Morrissey, 2017). The high rate of deforestation in Uganda has led to increased cost of biomass fuels, which together with increasing public awareness of climate change, has triggered a switch to more sustainable energy sources (Dhillion *et al*., 2003). Anaerobic digestion of organic wastes to produce biogas has been cited as one possible source of sustainable energy (Omar, 2015). However, biogas production competes with other livelihood activities (farm and non-farm) for labor, water and capital (Mwirigi *et al*., 2014; Kileo and Akyoo, 2014). This study focuses on the impact of biogas production on household labor allocation.

Due to constrained household resources, adoption of intensive technologies often requires a trade-off of resources from one activity to another (Ndandula, 2011). Labor is an important resource available to farmers (Sikei *et al*., 2009), and they channel it towards activities that bring more returns while not hindering other imperative activities. In a typical farm household, labor is required for tasks relating to biogas production, farm and non-farm activities. Tasks required for biogas production include collecting water, mixing feedstock and feeding the digester daily (Tucho *et al*., 2016). Farm related activities mainly include crop cultivation and animal rearing, while non-farm activities may include small side businesses (McCullough, 2017). Other resources used in biogas production include water (Mwirigi *et al*., 2014), animal wastes and crop residues (Patowary *et al*., 2016). Off-farm wastes, such as blood and rumen content from slaughterhouses, can also be used to produce biogas, the anaerobic process required to produce biogas potentially reducing the hazardous impact of pathogens in the environment (Abdeshahian *et al*., 2016).

Anaerobic digestion has two main products; fuel and slurry (Arsova, 2010). The slurry can be used on the farm as a fertilizer, while biogas is used by the household for cooking and lighting, both in the home and in animal housing (Arsova, 2010). Sales from crops and animals provide income to the household, which can also be used for off-farm purchases, feeding into both the household and the non-farm sector. Income from non-farm activities feeds back into the household, where it could be used to purchase more animals or do repairs on the biogas digester. Though not a focus in this study, land is also required for setting up the biogas plant, crop cultivation, animal grazing and animal structures. With this interdependence of resources and activities, farm households need to make decisions on where to allocate their precious labor resource and how much of it should be given to each activity.

Fig. 1: Inter-relationship between farm, biogas and non-farm activities



Households aim to maximize utility, and so allocate labor depending on the level of utility derived from each activity. However, there is little empirical evidence on the determinants of farm household labor allocation to biogas production, which makes it difficult for biogas technology promoters to enhance uptake of the technology. This study examines the factors influencing household labor allocation to farm, biogas production and non-farm activities.

2. Materials and Methods

2.1. Data collection

A household survey was conducted in Mpigi and Luwero districts of central Uganda in September 2014. Mpigi district is located in the West of Kampala, Uganda's capital city, whereas Luwero district is located in the North West of Kampala. Mpigi covers about 3,714 square kilometers while Luwero covers about 2,577.49 square kilometers. The total population of Luwero district was estimated at 456,958 and 250,548 for Mpigi district in 2014 (UBOS, 2017). Farming is the major livelihood activity in both districts and is dominated by small holder farmers. Firewood and charcoal are mainly used for cooking, while kerosene and solar energy are used for lighting. These districts were purposively selected because they have been targeted by NGOs promoting biogas technology. The households in Mpigi had a good number of functioning digesters, whereas most of the digesters in Luwero district households were non-functional. Therefore, this provided a strong basis for comparison of resource flows. A snow-balling method of sampling was used, where one respondent suggested another person who uses biogas technology to be included in the survey. Face to face interviews were guided by pre-tested questionnaires and this was followed by intense discussions and field observation. A total of 41 respondents who were currently using and 38 who had previously used biogas technology were interviewed.

2.2. Data analysis

Data was entered in SPSS (Statistical Package for Social Scientists) version 18 and later analyzed in STATA version 13. The study involved both qualitative and quantitative methods of analysis. Households were grouped based on their biogas digester status (functional, non-functional or without) and level of resource endowment. Means, standard deviations and independent t-tests were used to statistically compare the different households. In investigating the factors influencing labor allocation to farm, biogas and non-farm activities, this study drew from economic theory of farm households (Singh *et al*., 1986). The household model was used because it explicitly accounts for the fact that many low-income farm households are both producers and consumers of farm and other goods, and the markets for key factors and products are weak in rural areas of developing countries (Sikei *et al*., 2009). This means that specification of the production and consumption of subsistence households in most developing countries is interdependent and non-separable. The assumption of interdependence and thus non-separability of production and consumption imply that household resource allocation is decided simultaneously rather than recursively (Heltberg *et al*., 2000). The joint production and consumption of agricultural commodities and biogas products demands the use of a non-separable household model rather than a pure demand model (Singh *et al*., 1986).

2.3. Conceptual framework and empirical model

The model presented below assumes that members of the households are engaged in farm activities, biogas production activities and non-farm activities. The equations were adopted from Chang *et al*. (2012) in their study of labor supply, income and welfare of the farm household. The household maximizes utility by choosing labor allocation to specific activities, consumption and inputs. Therefore, the household solves,

$$\max\,(U) = U\big(C_j, N; H\big) \tag{1}$$

where U is the utility, dependent on consumption of commodities, C_j (where j = agricultural products (a), biogas products (b), or non-farm goods (o)), leisure activities, N, and H household characteristics that influence preferences. Household leisure, N, is not modeled since the leisure-labor margin in most rural households in Sub-Saharan Africa is negligible (Sikei *et al*., 2009).

The household maximizes utility subject to the production function for agricultural commodities, biogas products, and non-farm goods. Production for agricultural commodities, Q_a, is assumed to be a function of labor, L_a, purchased inputs such as fertilizer, X, and the household's land endowment, A_0,

$$Q_a = Q_a(L_a, X, A_0)\,. \tag{2}$$

The values for L_a, X and A_0 were obtained from the household survey.

Households use their own labor but may also hire-in some labor for agricultural production. Hired labor and household labor are assumed to be substitutable. Households are also assumed to be risk averse.

The production function for biogas products, Q_b, is assumed to be a function of labor used in production of biogas, L_b, the distance to the nearest water source, W, and the number of cattle owned by the household, K,

$$Q_b = Q_b(L_b, W, K). \tag{3}$$

The values for L_b, W and K were obtained from the household survey.

The production function for the non-farm goods, Q_o, is assumed to be only dependent on labor used in production L_0,

$$Q_o = Q_o(L_0). \tag{4}$$

The values for L_0 was obtained from the household survey.

The maximization of utility is solved using the method of Lagrange multipliers, constrained by household budget (Y).

Households are assumed to participate in competitive markets for agricultural products where they can buy and sell at a market price (P_j) which is assumed to be exogenous. Farm inputs (X) are assumed to be bought but not sold. Households may also buy and/or sell labor, L_v, at a market wage rate, v. The household budget constraint, Y, is therefore defined as

$$Y = \sum_j \left[\left(P_j Q_j - P_j C_j\right)\right] - P_x X + v L_v \tag{5}$$

where Q_j is the production function for agricultural products ($j = a$), biogas products ($j = b$), or non-farm goods ($j = o$), and P_x is the market price for farm inputs.

The labor market is very small, so vL_v is assumed to be negligible. Therefore, it is not necessary to determine the value of v.

Time available to the household, T, constrains available labor,

$$T - N = \sum_j L_j. \tag{6}$$

The Lagrangian for the household utility maximization is therefore

$$\mathrm{L} = U\left(C_j, T - \sum_j L_j\,; H\right)$$
$$+ \lambda\{[P_a Q_a(L_a, X, A_0) - P_a C_a] + [P_b Q_b(L_b, W, K) - P_b C_b] + [P_o Q_o(L_0) - P_0 C_0] - P_x X\} \quad (7)$$

where L is the Langrange function, and λ is the Lagrange multiplier.

After re-arranging the first order condition, the following expressions are derived;

$$dU(.)/_{dC_a} = \lambda P_a \quad (8)$$

$$dU(.)/_{dC_b} = \lambda P_b \quad (9)$$

$$dU(.)/_{dC_O} = \lambda P_o \quad (10)$$

$$dU(.)/_{dN} = \lambda P_a\, {}^{dQ_a(.)}/_{dL_a} \quad (11)$$

$$dU(.)/_{dN} = \lambda P_b\, {}^{dQ_b(.)}/_{dL_b} \quad (12)$$

$$dU(.)/_{dN} = \lambda P_o\, {}^{dQ_o(.)}/_{dL_o} \quad (13)$$

$$P_a\, {}^{dQ_a}/_{dX} = P_x \quad (14)$$

where $U(.)$ denotes the household utility function

Equations 8-14 indicate that, at the optimum, households allocate labor across activities so as to equalize the marginal value of household leisure with that of the time spent on each productive activity. In addition, at equilibrium, the ratios of marginal products of $C_a, C_b,$ and C_o, are equivalent to their price ratios. Expressions for labor supply, input demand and commodity demand can be derived as functions of all exogenous variables; P_j, H, A_0, W, K, T

In constructing the empirical model, labor shares were taken as dependent variables. The model is a system of three jointly estimated labor share equations. One equation is for biogas activities, the second is for agriculture activities and the third is for non-farm activities. Each labor share is a function of selected household characteristics. The model takes the following form, (Shively *et al.*, 2005);

$$L_{ij} = \alpha_i + \sum \beta_{ij} \log(P_j) + \theta_i A + \eta_i S + \gamma_i E + \mu_i A_0 + \Psi_i n + \delta_i W + \phi_i K + \varepsilon_i \qquad (15)$$

where subscript *i* represents the individual household and *j* represents different activities, L_{ij} is the labor share to each activity (hours), P_j is the labor return from each activity (Uganda shillings), *A* is the age of household head (years), *E* is the education of household head (years in school), A_0 is the size of land holding (ha), *S* is the sex of the household head, *n* is household size (number of household members available for labor), *W* is the distance to water source (m), *K* is the number of cattle owned by the household, ε_i is an error term, and α_i, β_{ij}, θ_i, η_i, γ_i, μ_i, Ψ_i, δ_i and ϕ_i are coefficients that reflect the importance of each household characteristic.

The age of household head (*A*), education (*E*), size of land holding (A_0), sex of household head (*S*), household size (*n*), distance to water source (*W*) and number of cattle owned (*K*) were obtained directly from the household survey.

In this study, the error terms across the equations in the system are correlated since the same explanatory variables and unobserved characteristics may influence the different equations. Therefore, estimating the individual equations using ordinary least-squares yields biased and inconsistent estimates (Woodridge, 2002). We therefore adopted the Seemingly Unrelated Regression model proposed by Zellner (1962) since it accounts for the cross-equation correlations. The merit of the Seemingly Unrelated Regression model is that it allows the estimation of the system of equations simultaneously, thereby controlling correlation across the error terms in the different equations.

3. Results and discussion

3.1. Characterization of farm households

Households were categorized in terms of the status of their biogas digesters; these included functional digester status and non-functional digester status. A total of 41 households had functional biogas digesters and 38 households had non-functional digesters. Results showed that men were the heads in the majority of households in both categories (71% for households with functioning biogas digesters and 63% for households with non-functioning biogas digesters). Household heads tend to have better understanding of resources in the household and they are mostly the final decision makers (UBOS, 2010). Arora and Rada (2013) asserted that one aspect of gender relations within rural households is that women do not control income generated through their labor, and so are resource constrained and income poor. Not having such power in the household limits the involvement of women into investment decisions regarding biogas technology. This was also highlighted by Mwirigi *et al*. (2014), who stated that the main causes of limited, little or no involvement of women in the decision for procurement of energy sources was low levels of income and control over productive resources.

The average age of household heads was 54.5 and 48.8 years for households with functional and non-functional digesters respectively. The high average age of the heads of households owning a biogas digester is because older household heads tend to have more resource endowment (in terms of livestock and income) compared to younger household heads, and so there is an automatic bias towards biogas digesters being installed in older headed households.

The average number of years of schooling was 10 for households with functional digesters and 6 for those with non-functional digesters as shown in Table 1.

Table 1: Socio-economic characteristics of households with functional digesters and non-functional digesters

	Non-functional digester		**Functional digester**	
	Mean	**Std deviation**	**Mean**	**Std deviation**
Age-household head (years)	49	13	55	12
Education of household head (years)	7	3	11	3
Household size	6	3	7	3
Total land (hectares)	2	1.5	3	3.3
Crop land (hectares)	1.2	0.9	1.1	1
Grazing land (hectares)	0.1	0.2	0.3	0.6
Biogas land (sq meters)	5	13	10	47

3.2. Inventory of household resources

The main household resources were land, labor, livestock and crops. The average resource ownership is summarized in Table 2. There was a significant statistical difference in the number of cattle and pigs owned by households with functional digesters compared to those with non-functional digesters.

Table 2: Household resource endowment by households with and without digesters

Household resource type	Average for functional digesters (n=41)	Average for non-functional digesters (n=38)	Mean difference for functional vs. non-functional
Land (hectares)	2.6	2.1	0.5
Labor (numbers[1])	6.2	4.2	2.0***
Cattle (numbers)	3.9	1.5	2.5***
Pigs (numbers)	7.3	2.9	4.3**
Goats (numbers)	1.9	1.4	0.5

***, **,* Significant at 1%, 5% and 10% respectivelynumbers[1], number of adult equivalent in the household

Households with functional digesters had more cattle and pigs compared to their counterparts with non-functional digesters. This emphasizes the role of feedstock in adoption of biogas technology. Other studies, such as Pandey *et al*. (2007), have noted that cattle and pigs are the major sources of feedstock for a biogas digester. Christiansen and Herltberg (2012) concluded that the suspension of biogas in China was due to lack of or too few animals at some point of the year.

3.3. Determinants of household labor allocation

Table 3 shows the summary statistics of the returns from each activity, while table 4 shows factors that influence household labor allocation to biogas, farm and non-farm activities. The Breusch-Pagan test was employed to test the null hypothesis that the error terms of the equations in the system are independent. The results of the test showed that $x^2(3) = 10.190$; Pr = 0.017, and therefore the null hypothesis of independence of errors across equations is rejected and hence, the use of Seemingly Unrelated Regression model to estimate the equation is justified.

Table 3: Summary statistics for returns to farm, non-farm and biogas activities

Variable definition	**Log of average returns (UGX)**	**Standard deviation**
Farm activities labor returns	3.2	1.1
Non-farm activities labor returns	2.2	1.5
Biogas activities labor returns	2.0	1.3

The returns from labor were converted to logs to ensure normal distribution of activity labor returns. This gave an insight into the returns from each activity and how much a household is likely to forego if it chooses to devote part of its time to biogas activities. Farming had the highest average return, about 64% higher than biogas and 46% higher than non-farm activities.

Table 4: Factors influencing household labor allocation to biogas, farm and non-farm activities

	Farm labor share	**Z-statistics**	**Non-farm labor share**	**Z-statistics**	**Biogas labor share**	**Z-statistics**
Constant	**-2.35859**		**-2.91165**		**0.697311**	
Farm activity labor returns	2.951***	6.74	-0.166	-0.54	-0.056	-0.61
Off farm activity labor returns	0.112	0.38	1.324***	6.42	0.053	0.84
Biogas activity labor returns	-0.745**	-2.06	0.121	0.48	0.465***	6.09
Age of household head	0.006	0.19	0.065***	2.75	-0.011	-1.53
Sex of household head (male)	-1.407	-1.6	0.741	1.21	-0.626***	-3.37
Education of household head	0.092	0.83	0.107	1.39	0.001	0.05
Household size	0.034	0.24	-0.248**	-2.5	0.004	0.13
Size of land holding	-0.031	-0.28	-0.239***	-3.11	0.014	0.59
Number of cattle	0.294**	2.48	0.088	1.06	0.123***	4.91
Distance to water source	-0.001	-1.11	1.47E-05	0.03	-0.001***	-2.98
Breusch-Pagan test (x^2)	10.190**					

*****, **,* Significance at 1%, 5% and 10% respectively**

3.3.1 Activity labor return, cross-labor return and labor share

Activity labor returns show positive relationships with the labor share for the activity, indicating that households obtaining higher returns from an activity allocate a larger share of labor to it. However, cross-labor returns between the different activities were negatively related because an increase in returns of one activity reduced labor allocation to other activities. For example, if returns from biogas increase, then households were more likely to increase labor allocation to biogas activities. Therefore, households respond positively to increase in activity returns. This is consistent with findings by Sikei *et al*. (2009) on returns from agriculture, non-farm and forest products.

3.3.2 Age

Age had a positive and significant (1% level of significance) impact on non-farm labor share. This is because older members tend to diversify their income to accumulate as much wealth as possible. As a result, they allocate more labor to non-farm activities. Age is negative and insignificant in biogas labor share. Older household heads were less likely to allocate their labor to biogas; this is because older members may not have the energy to carry out extra activities associated with biogas, such as collecting water, mixing dung, and cleaning the digester. This is consistent with findings from (Parawira, 2009) who stated that some older members without young care takers may not be in a position to take care of animals which are the major source of feed stock for the digester.

3.3.3 Size of land holding

Size of land holding had a negative and significant impact on non-farm activity labor share (1% level of significance). The larger the land size, the less households allocate labor non-farm. This is consistent with findings from Bagamba *et al*. (2007) who stated that farm size is negatively related to amount of time allocated to non-farm activities. Matshe and Young, (2004) noted that farmers undertake non-farm activities because of constraints in getting access to farming land. Larger land holdings require more labor than small ones. Therefore households tended to spend more time working on their own land than diverting labor to other activities. However, size of land holding had no effect on labor supplied to farm and biogas. This is because land is not a major resource in biogas production. This is comparable to findings from Bagamba *et al*. (2009) who concluded that farm size had no effect on labor supply. Hari and Ainun (2013) also found that size of land holding had no effect on labor allocation to farm activities.

3.3.4 Sex of household head

Sex of the household head had a negative and significant (1% level of significance) impact on biogas labor share. This result implies that being a male decreases labor allocation to biogas activities. Biogas in rural households is mainly used for cooking (Kileo and Akyoo, 2014); as a result, men do not see it as a priority in the household because they do not work in the kitchen as much as women. Results show that 95% of the cooking was done by women and children and only 5% is done by men. Kileo and Akyoo, (2014) further note that a biogas system provides a direct benefit to the women and female children by reducing the drudgery and danger to personal safety related with collecting fuel wood; as a result, female headed households will allocate more labor to biogas production than their male counterparts. Women in male headed households have less control over resources and thus cannot make strong decisions in the households, such as where to allocate household labor. Therefore, female headed households tended to allocate more labor to biogas activities than male headed households. However, sex of the household head was not significant in farm and non-farm activities. This is also consistent with findings from Bagamba *et al.*, (2007), who stated that gender had no significant effect on time allocated to farm production and being male increases the chance of working on non-farm activities but decreases the time in home production activities.

3.3.5 Household size

The number of household members available for labor had a negative and significant (5% level of significance) impact on non-farm labor share but a non-significant impact on farm and biogas labor shares. This implies that households with more members will allocate less labor to non-farm activities. However, Matshe and Young (2004) noted that household size had a positive effect on non-farm labor allocation while Sikei, (2009) found no significant relationship between household size and non-farm labor share.

3.3.6 Number of cattle owned

The number of cattle owned by the household had a positive and significant impact on farm (5% level of significance) and biogas (1% level of significance) labor share equations. Households with more cattle tend to have more farm related activities compared to their counterparts with less cattle. Therefore, more labor is allocated to the farm. By contrast, Utami and Seruni (2013) noted that increasing number of cattle had little impact on additional household labor requirements on a per farm basis; as herd size increases by 50% about 14% additional household labor would be required. It is also clear that households with more cattle tend to have more feed stock and thus can produce biogas more frequently (Walekhwa *et al*., 2009). Labor is required for the daily maintenance of the digester (daily mixing and feeding of the digester), therefore households with more cattle are more likely to allocate labor to biogas activities.

3.3.7 Distance to water source

Distance to water source had a negative and significant (1% level of significance) impact on the biogas labor share equation. Water is a key factor in biogas production, so its availability is of paramount importance (Mwirigi *et al*., 2014). Rutamu, (1999) reported that a typical cow drinks 60 liters of water per day and a further 60 liters of water are required for mixing feed stock. The larger the distance to water source, the less the households will engage in biogas activities as water collection will consume much of their precious time. Abadi and Gabrehiwot, (2014) also found a negative relationship between distance to water source and use of biogas technology in Ethiopia. Therefore, households that are very far from water sources allocate less labor to biogas activities. A study by Pandey *et al*. (2007) suggested that biogas is feasible in households with less than 1 km distance to water sources.

4. Conclusions

Factors influencing labor allocation to farm, biogas and non-farm activities included activity labor returns, age of the household head, sex of the household head, number of household members available for labor (size of family labor), size of land holding, number of cattle owned by the household and distance to the nearest water source. Increases in own activity labor returns increases allocation of labor to that activity. Female headed households allocate some of their labor to biogas activities. Households with more cattle allocate their labor to farm and biogas activities due to ease of access to feedstock. Households with easy access to water also allocate some of their labor to biogas production, since they spend less time searching for water. This means that households close to water sources and/or those that practice water harvesting are in a better position to allocate some labor to biogas and use the other portion of their labor for other livelihood activities without constraining any of the household day to day activities. Age of the household head had no significant influence on labor allocation to biogas activities though it positively influenced labor allocation to non-farm activities. Size of land holding also had no significant effect on labor allocation to farm and biogas activities though it negatively influenced labor allocation to non-farm activities.

Based on the study findings, we recommend that in choosing the households where biogas digesters should be installed, biogas promoters should carefully assess the level of resource endowment by these households through baseline studies. Special attention should be given to quantifying available resources, such as size of household labor, quantity of feedstock and availability of water since these are the major resource requirements for biogas production.

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