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Utilization of Livestock Manure Based Biogas for Climate Change Mitigation in Nakuru County, Kenya

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ABSTRACT

Burning of wood fuel degrades forests, causes indoor household air pollution and releases greenhouse gases contributing to deforestation and climate change. Livestock manure decomposes anaerobically producing greenhouse gases. Comparative study of wood fuel usage and Methane emissions from wood stove user households and biogas cook-stove user households was conducted in Nakuru County, Kenya. The study aimed at determining the wood fuel and biogas usage in households of Nakuru County and estimating reduced wood fuel usage and Methane emissions amounts from use of biogas as a way of mitigating climate change. The study also, examined how biogas use contributes to the improvement of household livelihoods. One hundred and twenty one dairy cattle farmer households (HHs) were clustered into 5 regions and purposively sampled into wood stove user households and biogas cook-stove user households. The study used survey research design where data was collected using questionnaire and key informant interview. Results indicated that mean annual wood fuel usage for wood stove user HHs and biogas cook-stove user HHs was equivalent to 14 and 7 mature trees respectively. The mean biogas usage for biogas cook-stove user households was 481.6 m^3 per year. Maximum values of Methane emissions from wood stove user households and biogas cook-stove user households were 2048 and 956 $KgCO_2e$/HH/year respectively. It was estimated that about 50-53% of Methane emissions from wood fuel usage can be reduced by using biogas cook-stoves. Reduced wood fuel usage of 3899.4 Kg/HH/year due to biogas use translated to conserving 8 mature trees per household per year. The conserved trees can absorb additional 6433.99 -7018.90 Kg of Carbon dioxide per year. Biogas utilization could therefore be a good option for reducing deforestation and Methane emissions in the context of climate change.

1. Introduction

Livestock production under rain-fed agriculture system is diminishing due to unreliable rains in Kenya. Frequent droughts associated with changes in climate have affected livestock production. This can be solved by livestock keepers understanding the seasonality schedule and clearly planning production activities (Gioto et al., 2017). In livestock keeping, the farm animals are fed organic materials and they produce waste known as farmyard manure. This organic waste decomposes anaerobically to produce Methane and Nitrous oxide which are strong greenhouse gases (GHGs) that cause global warming and climate change. Atmospheric concentration of Methane has increased by about 154% since pre-industrial time reaching 1834 parts per billion in 2015 (Saunois et al., 2016). Another source of Methane emissions and other GHGs such as Carbon dioxide (CO_2) is burning of wood fuel. Well mixed greenhouse gases have positive radiative forcing resulting to warming of the earth's surface and other components of the climate system because outgoing infrared radiations are retained in the atmosphere. United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a shift of climate conditions that is attributed directly or indirectly to human activities that alter the composition of the atmosphere and to which is in addition to natural climate variability observed over comparable period of time. Global warming potential of Methane is 84 times that of Carbon dioxide over time horizon of 20 years. Therefore Methane traps 84 times more heat in the atmosphere than Carbon dioxide (IPCC, 2013; Onwumelu et al., 2009).

Wood fuel production entails cutting down trees in the forests for use in wood stoves. There is clearing of forestlands, less vegetation cover, continuous emissions of GHGs and other pollutants to the atmosphere consequently contributing to climate change.

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Burning of wood fuel for cooking increases indoor household air pollution. It produces air pollutants such as particulate matter, black carbon, Carbon monoxide, Nitrogen dioxide and formaldehyde. Exposure to these pollutants causes respiratory ill health to women and children (Pant, 2008). Reducing indoor air pollution contributes to Sustainable Development Goals (SDGs) of making cities and human settlement safe, resilient and sustainable by paying special attention to improved air quality. Other SDGs targets that can be achieved from the findings of this paper include sustainable management of forests, fighting climate change and renewable energy (UNDP, 2015). Agriculture production has experienced effects of climate change such as prolonged droughts, frequent flooding, heat waves, and growing invasion of pests and diseases (FAO, 2012; Aggarwal, 2008). Replacing wood fuel with better alternatives is the best strategy of slowing climate change. When wood fuel is substituted by biogas technologies, the energy produced is clean and renewable (Pant, 2008; Alexandre and Walter, 2015; Sharma et al., 2016). Use of biogas in cooking reduces indoor household air pollution and decreases respiratory diseases since it burns without smoke and there are reduced air pollutants. Utilization of biogas as fuel reduces Methane emissions from wood cook stoves and livestock manure. GHGs associated with livestock can be managed by livestock farmers through biogas production from livestock manure. Biogas production entails feeding a biodigester with livestock manure where anaerobic digestion takes place to produce Methane rich biogas fuel and nutrient rich bio-fertilizer. Biogas production is based on principles of anaerobic digestion namely; hydrolysis, acidogenesis, acetogenesis and methanogenesis (Onwumelu et al., 2009; Holmes and Smith, 2016).

Biogas production and use mitigate climate change by reducing deforestation, enhancing conserved forests as carbon sink, and reducing GHG emissions such as Methane and Nitrous oxide. Biogas system conserves the forests by reducing the cutting of trees for wood fuel production since biogas is used as cooking fuel. Use of biogas cook-stoves minimizes Methane emissions by directly destroying Methane during burning of the biogas fuel. When biogas is used as cooking fuel, Methane emissions from wood fuel burning is reduced or avoided. When bio-fertilizer is used in farms to improve soil fertility, it avoids Nitrous oxide from nitrogenous chemical fertilizers application (Teenstra et al., 2016; Tilley et al., 2014). Substantial research has been done over Kenya on biogas production, but little work has been done to evaluate the relationship between biogas and climate change mitigation among livestock keepers (GTZ, 2010; Nzila, 2017; Nyang'au et al., 2016; KARI, 2003). The focus of this study was to incorporate biogas use in reduction of GHGs emissions and increase climate change mitigation capacity of Kenyans. The objectives were to determine the wood fuel and biogas usage for households, estimate reduced wood fuel usage and Methane emissions due to use of biogas for mitigating climate change, and examine how the use of biogas could contribute to the improvement of households' livelihoods in Nakuru County.

2. Data and Methods

The area selected for this study was Nakuru County which is located in the South Rift region of Kenya. It is situated in the equatorial zone as it lies between latitude 1.16°S and 0.22°N and longitude 35.42°E and 35.58°E. It borders eight Sub Counties as shown in Figure 1. It borders Kericho and Bomet to the West, Narok to the South West, Baringo to the North, Kajiado to the South, Kiambu to the South East, Nyandarua to the East and Laikipia to the North East. The study area is 7495 km2 with population of 1,603,625 people from 409,836 households as per Kenya National Population Household Census of 2009. Livelihood types in the County include agriculture, mining, fishing and tourism. The area has bimodal rainfall pattern having long and short rains seasons (CEDGG and AK, 2014).

Primary data collected from households was wood fuel and biogas usage. Daily quantity of wood fuel used by households (HHs) included amounts of firewood and charcoal which were measured using weighing scale. The daily volume of biogas used was determined by number of hours in a day in which the biogas cook-stove was turned on. These measurements were then used to estimate the mean annual wood fuel and biogas usage by the households in Nakuru County. The amount of wood fuel usage reduced through use of biogas was estimated from the difference between average quantity of wood fuel used by wood stove user and biogas cook-stove user households. Equation (1) was used to compute the quantity of Methane emissions from burning of wood fuel for sample households in Kg of CO_2 equivalent ($KgCO_2e$).

$$E_W = \frac{1}{n}\sum_{i=1}^{n} U_i(EF_{CH4} \times GWP_{CH4}) \qquad (1)$$

Where E_W is Methane emissions in Kg of CO_2 equivalent from burning of wood fuel, n is the total number of sample households, U_i is the quantity of annual wood fuel usage in Kg by a sample household, EF_{CH4} is the Emission Factor of Methane for wood fuel, and GWP_{CH4} is the Global Warming Potential of Methane.

Reduced Methane emissions caused by biogas use were obtained by computing the difference between mean Methane emissions from wood stove user HHs and biogas cook-stove user HHs. During administration of questionnaire, the respondents were asked the effects of using biogas fuel on their health and livelihoods.

The research design used in the study was survey. Data was systematically collected using questionnaire and key informant interview. The instruments of research were pre-tested. One hundred and twenty one (121) dairy cattle farmer households were sampled in Nakuru County. The households were clustered into 5 regions and purposively sampled into 62 wood stove user HHs and 59 biogas cook-stove users HHs. The five regions were Subukia, Bahati, Rongai, Njoro and Molo as shown in Figure 1. The units of analysis were households. Households using biogas cook-stove were defined as treatment group while those households using wood stove were control group. Households that used both biogas and wood stoves were considered as biogas cook-stove user households.

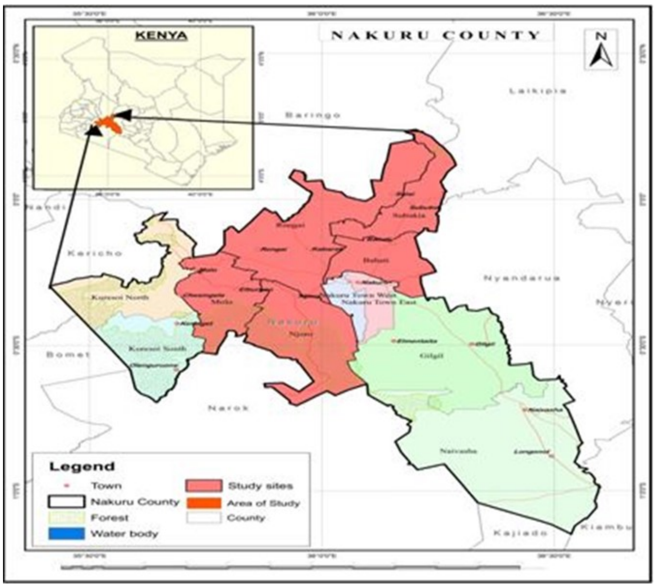

Figure 1: Map showing location of study sites in Nakuru County (Source: Samali, 2018)

The hypothesis that the use of biogas does not reduce woodfuel usage and Methane emissions from woodfuel cook-stove and livestock manure in Nakuru County was tested. T-test was performed to analyze the difference in mean woodfuel usage between wood stove user and biogas cook-stove user households at 95% confidence level. The physical variables on biogas and woodfuel were analyzed by descriptive analysis and inferential statistics. The limitation of this study was it used purposive sampling which focused more on sampling respondents from sub-Counties and wards with higher biogas plants installation. Purposive sampling is one of the non-probability sampling methods where each respondent in the sample does not have the same probability of being chosen from the population but inclusion of the respondent is based convenience of the researcher when interested in promoting new technology.

3. Results and Discussion

The results from this study highlighted the contribution of biogas utilization on Methane emissions reduction for climate change mitigation in Nakuru County; Kenya. Compared to the mean annual woodfuel usage for households in control group (7314.5 Kg/year), the households in the treatment group were associated with lower mean annual woodfuel usage (3415.1 Kg/year). The difference in mean woodfuel usage between wood stove and biogas cook-stove user households was highly significant at 95% confidence interval. Each biogas cook-stove user household used 481.6 m^3 of biogas per year as indicated in Table 1. In comparison with wood stove user households, the study found that biogas cook -stove user HHs were associated with lower woodfuel usage. Each of the wood stove user HHs cut down an equivalent of 14 mature trees per year compared to 7 mature trees per year by biogas cook-stove user HHs for woodfuel production. The use of woodfuel destroys forests. Adoption of biogas technology by biogas cook-stove user households resulted to 53.3% reduction (7314.5 versus 3415.1 Kg/HH/year) in woodfuel usage. Reduced woodfuel usage of 3899.4 Kg/HH/year due to use of biogas translated to conservation of 8 mature trees per HH per year from being cut down for woodfuel production. The test of significance from t-test showed that the difference in mean annual woodfuel usage between the wood stove user households and biogas cook-stove user households was highly significant at 95% confidence level for independent samples test. The p-value associated with the t-test was 0.000 implying that the difference in means of the two types of stove user households was highly significant at 0.05 level (Table 1). This observation on woodfuel reduction was consistent with study evidence from Nepal and Ethiopia (Chand et.al., 2012; Amare, 2014). Biogas cook-stove user households "stack" stoves that is they used biogas and wood stoves concurrently. Only four households used biogas cook-stoves exclusively among dairy cattle farmer households (Plate 1). Majority of the households used wood stoves (96.7%) enhancing deforestation and Methane emissions from wood fuel (Plate 2).

Plate 1: Biogas cook-stove with regulator (red in colour)

Table 1:Descriptive statistics for (a) Wood and biogas cook-stove user households (b) Wood stove user households and (c) Biogas cook-stove user households

	(a) Wood and biogas cook-stove user HHs		(b) Wood stove user HHs		(c) Biogas cook-stove user HHs		
Variables	Mean (S.D.)[b]	Observations	Mean	Observations	Mean (S.D.)[b]	Observations	p-value
Wood fuel usage (Kg/HH/year)	5481.4 (5261.2)	117	7314.5 (6217.1)	62	3415.1(2755.3)	55	<0.000
Biogas usage (m^3/HH/year)	-	-	-	-	481.6(268.6)	57	-

[a] p value is from two-sided t-tests difference in means between (b) and (c) for wood fuel usage ($p<0.05$)

[b] S.D: Standard Deviation

Plate 2: Clay lined wood stove (Source: Samali, 2018)

Methane emissions levels from wood stove user households was between 1228.83 and 2048.05 $KgCO_2e$/HH/year compared to between 573.74 and 956.23 $KgCO_2e$/HH/year among biogas cook-stove user households. The results illustrated two types of household energy where wood fuel user households released higher amounts of Methane emissions than biogas fuel user households. Figure 2 shows maximum Methane emissions by wood stove user and biogas cook-stove user households as 2048.05 and 956.23 $KgCO_2e$/HH/year respectively. There was significantly higher level of maximum Methane emissions associated with wood stove user households compared to biogas cook-stove user households.

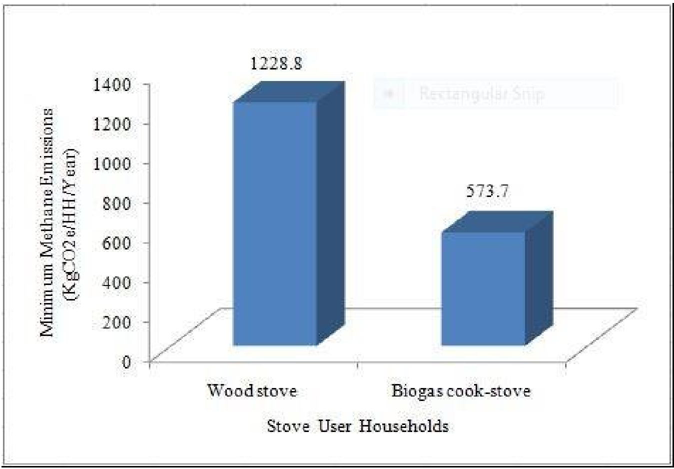

Figure 2: Mean maximum Methane emissions by type of energy stove source *(Source: Samali, 2018)*

Figure 3 indicates minimum Methane emissions by wood stove user and biogas cook-stove user households as 1228.83 and 573.74 $KgCO_2e$/HH/year respectively. There was significantly lower level of minimum Methane emissions by biogas cook-stove user households compared to wood stove user households. The conserved (8 mature trees per HH per year) trees due to use of biogas absorbed additional 6433.99 - 7018.90 Kg of Carbon dioxide per year. The best practice of afforestation for each dairy cattle farmer household in the study area is planting at least 8 tree seedlings per year so as to conserve farm forests and sequester carbon. This could lead to enhanced climate change mitigation since conserved trees increase the capacity of forests to absorb Carbon dioxide from the atmosphere and Methane emissions from wood fuel is minimized through reduced wood fuel usage. Biogas digester convert livestock manure to produce clean energy in form of Methane rich biogas. 289 m^3 of Methane was destroyed by each biogas cook-stove user households per year during cooking and heating as they used biogas fuel. Burning biogas converts Methane into Carbon dioxide thus reduce the climate impact of Methane in terms of global warming and climate change. Analysis of Methane emissions showed that Methane emissions released by wood stove user HHs was different from biogas cook-stove user HHs. The biogas cook-stove user HHs had lower amounts of Methane emissions than wood stove user HHs by 665.09-1091.82 $KgCO_2e$/HH/year. Utilization of biogas cook-stove was associated with 53.3% reduction in Methane emissions compared to using wood stove. Significant portion of Methane emissions caused by wood fuel use could be reduced by installing biogas system. This implied that the use of biogas fuel contributes positively to climate change mitigation by releasing significantly low Methane emissions to the atmosphere compared to wood fuel.

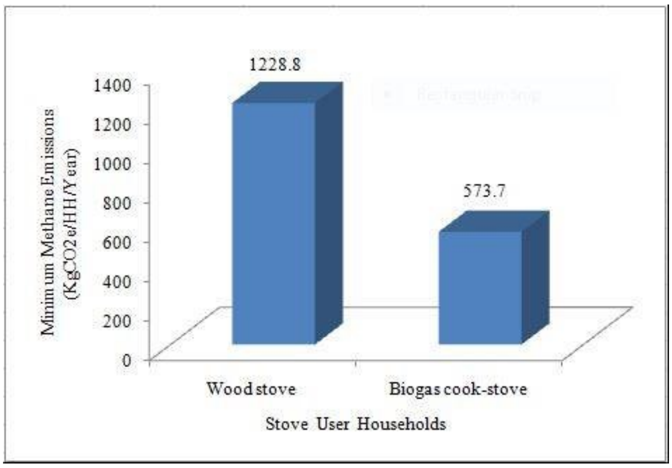

Figure 3: Mean minimum Methane emissions by type of energy stove source *(Source: Samali, 2018)*

Figure 4 shows the effects of biogas installation in the household among the respondents where 28.9%, 28.1%, 20.7%, 19%, and 3.3% observed reduced coughs, eye problems, headaches, chest pains and diarrheal diseases respectively. Installation of biogas reduced occurrence of diseases such as eye problems, diarrheal diseases, coughs, headaches and chest pains. Reduced coughs were highly associated to biogas installation and the least association was observed on diarrheal diseases. Smokeless biogas fuel improved household air quality leading to reduced respiratory diseases in the HHs. Biogas use has no pollutants that are usually associated to wood fuel combustion. Figure 5 indicates respondents strongly agreed that biogas technology reduced smoke related diseases (74.1%), saved money from not buying mineral fertilizers (55.2%), empowered women and children by saving time in cleaning utensils, cooking and not collecting firewood (55.2%). The effects of biogas technology on employment to the youths, the respondents strongly disagreed (29.3%), agreed (27.6%), disagreed (15.5%), neutral and strongly agreed (13.8% each). About three quarters of the respondents strongly agreed that the use of biogas cook-stove reduced smoke related diseases.

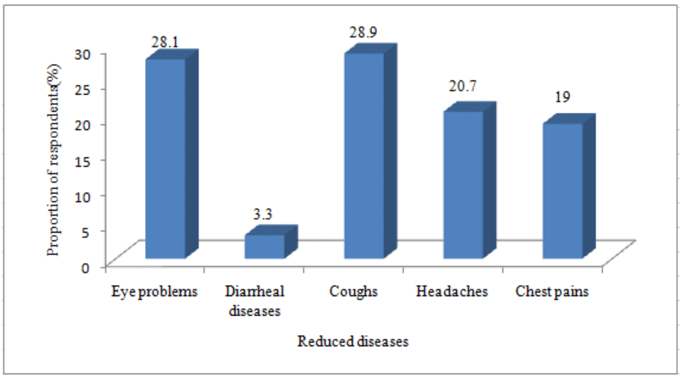

Figure 4: Reduction in human diseases after biogas installation *(Source: Samali, 2018)*

Wood smoke related diseases include coughs, eye problems, chest pains and headaches. More than half of the respondents (55.2%) saved money from not buying chemical fertilizers such as Diammonium Phosphate, Calcium Ammonium Nitrate and Murate of Potash because they used bio-fertilizer from biogas digesters for crop production. The women and children saved time during firewood collection, cooking and cleaning utensils. Time was saved because women and children do not fetch firewood from the forests since biogas fuel is available at their doorstep. They also spend little time cooking and cleaning utensils because biogas fuel does not form black soot on the utensils. Construction and maintenance of biogas plants provide employment to limited number of youths as sale persons, artisans and caretakers of the digesters. The findings of the study illustrated the aspects of conserved forests, reduced Methane emissions and smoke related diseases due to utilization of biogas. Biogas technology is one of the good options of reducing wood fuel induced greenhouse gases and global warming for climate change mitigation.

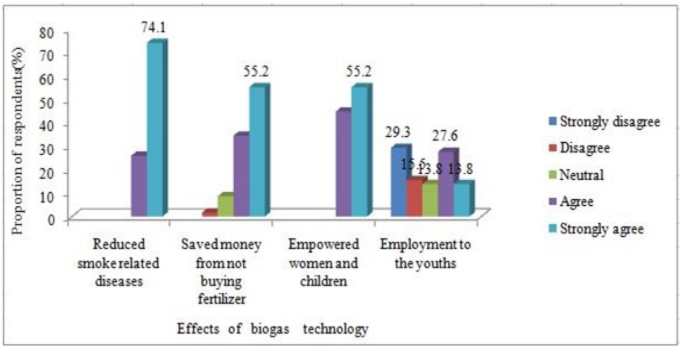

Figure 5: Assessment on the effects of biogas technology in the household *(Source: Samali, 2018)*

4. Conclusions and Recommendations

Mean annual wood fuel usage of wood stove user HHs and biogas cook-stove user HHs was 7315.4 Kg/year and 3415.1 Kg/year respectively. The use of biogas cook-stove was associated with low wood fuel usage and Methane emissions compared to the use of wood stove. The t-test showed difference in mean annual wood fuel usage between biogas cook-stove user and wood stove user households was significant for 95% confidence interval at $p<0.05$ level. Adoption of biogas cook-stove use resulted in 53.3% reduction in wood fuel usage (7314.5 versus 3415.1 Kg/HH/year) and Methane emissions (2048.1 versus 956.2 $KgCO_2e$/HH/year). Burning biogas converts Methane into Carbon dioxide thus reduce the climate impact of Methane in terms of global warming potential and climate change. Replacing wood fuel with biogas conserves forests consequently enhancing the capacity of forests for carbon sink. The conserved trees resulting from use of biogas cook-stoves absorbs between 6433.99 and 7018.90 Kg of Carbon dioxide per year. The study have shown that there is need to integrate biogas production and use in crop and livestock farming to enable reduce deforestation and minimize Methane emissions consequently slowing climate change. The findings of this study suggests that biogas programme benefitted small scale dairy farmers' households in improving indoor household air quality, reducing wood fuel usage and Methane emissions hence mitigating climate change.

Up-scaling biogas use would reduce Methane and Carbon dioxide emissions in effort to combat climate change through mitigation programs. The following actions are necessary for scaling up of biogas production and use in Kenya.

1. Education and awareness creation on biogas utilization and Climate change for rural and urban population.

2. Promotion of anaerobic digesters for treatment of livestock manure through increased resource mobilization and access for biogas programs.

3. Dissemination of biogas technology to all levels of community.

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