22E05

Life cycle assessment of biogas used for the provision of thermal household energy in developing countries

J.Lansche*, S.Schock*, J.Müller*

Universität Hohenheim, Institute of Agricultural Engineering, Tropics and Subtropics Group, Stuttgart, Germany
(e-mail: j.lansche@uni-hohenheim.de).

Corresponding Author M.Sc. Jens Lansche, Universität Hohenheim, Institute of Agricultural Engineering, Tropics and Subtropics Group , Garbenstr. 9, 70599 Stuttgart, Tel.: +49(0)711/45923112, Fax: +49(0)711/45923298, e-mail: j.lansche@uni-hohenheim.de

Abstract: The utilization of dried dung as fuel for household cooking stoves is very common in rural areas of developing countries. The objective of this study was to compare the environmental impacts for the provision of cooking heat from biogas with the utilization of dung cakes. For this purpose, the method of life cycle assessment was used for assessing the impact categories global warming potential, acidification potential, eutrophication potential and human toxicity potential. The results show that anaerobic digestion at household scale can contribute to the reduction of greenhouse gases (GHG's) as well as several other emissions in rural areas.

***Keywords**:* Biogas, dung combustion, GHG emissions, LCA,

1. INTRODUCTION

The utilization of dried dung cakes as fuel for household cooking stoves is very common in rural areas of several developing countries, e.g. Ethiopia. The emissions caused thereby contribute to the global warming potential, endanger the human health of the local people and can enforce other environmental problems in the field of eutrophication and acidification. There is a strong relation between exposure to smoke from biomass combustion and acute respiratory infections (ARI), other lung or eye diseases. Children exposed to smoke from biomass fuels show a significant higher risk in ARI than children less exposed and/or coming from households where cleaner fuels are used (Smith *et al.* 2000). A study conducted in Gambia had the finding that girls under 5 years, which are raised by mothers cooking, compared to girls raised by smoking parents, had a six times higher risk of acute respiratory infections. Suspended particulate matter and products of incomplete combustion are highly problematic in this respect (Schwela 1997). These emissions can be reduced considerably by the use of biogas stoves. An efficient way to minimize GHG emissions and to preserve nutrients for plant production is biogas production by anaerobic digestion as it is done in industrialized countries in Europe with a relatively high technical standard. The biogas plants in developing countries are much smaller in general and other construction types and materials are used. Another important difference is that biogas in industrialized countries is mainly used in combined heat and power plants. Hence the reduction potential for the biogas system in the system under research can differ from the values that were found for biogas systems in Europe.

2. MATERIALS AND METHODS

The objective of this study was to assess the environmental impacts for the provision of household cooking heat in rural areas of developing countries on the example of Ethiopia. For this purpose the method of life cycle assessment was used according to ISO 14040 and 14044 standards. This method allows the consideration of the whole life-cycle of a product from cradle to grave. Two systems are considered. One is characterized by the provision of cooking energy through the use of cattle dung which is collected, dried and used as solid fuel. The system to be compared with is the production of biogas by the use of anaerobic digestion technology, including the utilization in a biogas stove. The digester model used in the study region is mainly a modified fixed dome model named “Sinidu” which originates from a model used in the Nepalese biogas program. The plant sizes in the study area are mainly 6 or 8 m^3 (Gwavuya 2010). The digesters are fed with dung collected on the grazing area or in the houses used for overnight stabling. Approximately the same amount of water is added to dilute the feedstock. The energy consumed by the household is provided through the combustion of the produced biogas in a stove or lamp. Life cycle inventory was based on literature values e.g. for emissions of dung cake combustion and methane conversion factors. Impact assessment was done using the CML 2001 method in the version of 2007 for the impact categories global warming potential, acidification potential, eutrophication potential and human toxicity potential. Table 1 shows inventory parameters which are considered for each impact category.

Table 1 Considered environmental impact categories

Impact category	Unit of the indicator	Inventory parameter
Global warming potential (GWP_{100})	CO_2 equivalents	CO_2, N_2O, CH_4
Acidification potential (AP)	SO_2 equivalents	SO_2, NO_X, NH_3
Eutrophication potential(EP)	PO_4^{3-} equivalents	NO_X, NH_3, N_2O
Human toxicity potential (HTP)	DCB equivalents	NMVOC, SO_2, NO_X, NH_3, TSP

3. RESULTS

Global Warming Potential (GWP)

The results show that the total amount of CO_2 equivalents emitted by the production of 1 MJ heat energy delivered to pot is 45% lower for the biogas system compared to the dung combustion system (Figure 1). Livestock contributes the most to the GWP in both production systems. In the biogas production system it has a share of 71% to the total GWP. For the dung combustion system the share is 60%. The main emission source for both systems is CH_4 from enteric fermentation. Low emissions occur from direct dung management. High emissions originate in the biogas system from the digester in terms of diffuse biogas emissions and the slurry displacement chamber in terms of CH_4, which in total accounts for 18% of the total GWP of the system Low emissions relevant to GWP occur from drying dung for the production of dung cake, resulting from N_2O.

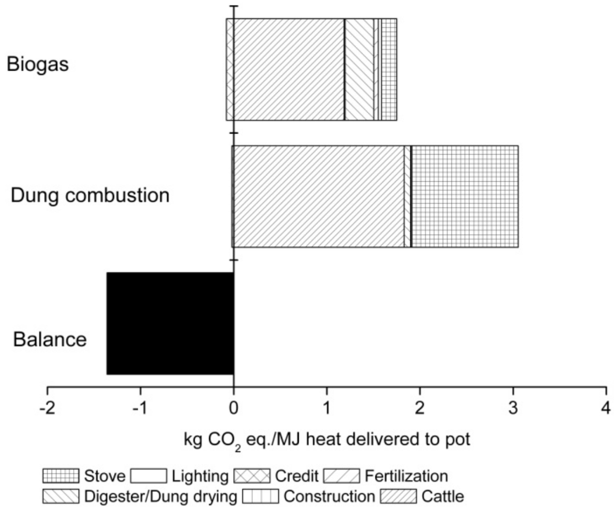

Figure 1: Global warming potential

The second dominant source of emissions contributing to GWP in the dung combustion system is the dung stove which attributes to a total of 38%. The emissions caused by the stove contribute to 9% to the total GWP. Main gases are CO_2 and N_2O. Credits given for fertilization have only a small effect. In the biogas system they have an effect of -5% of total GWP. The dung combustion scenario receives a credit of 0.006% only. From the above observation it can be stated that the main driving factors behind the GWP are livestock farming and the combustion process for the dung combustion system. These factors are driven by the combustion efficiency of the stove, the energy content of the fuel and the corresponding fuel consumption which has an increasing effect on the processes further upstream in the production system. In the biogas scenario CH_4 emissions from the digester are the second largest emission source

Eutrophication Potential (EP)

Alike in GWP, livestock contributes to EP with a high share in both systems; 75% in the biogas system and 45% in the dung combustion system (Figure 2). NH_3 loss from dung and urine is the main cause for these emissions. The second largest contributor in the biogas system is the slurry fertilization (41%). NH_3 accounts for more than 96%. The same holds true for the credit given in terms of mineral fertilizer. The largest share of the credit is contributed by emissions related to the application in form of NH_3 (78%). Less than 15% result from the production and transport.

Dung drying accounts for 46% of the total EP caused by the system, which is the largest fraction. Most of it is caused by NH_3 (98%), followed by nitrous oxide (2%).

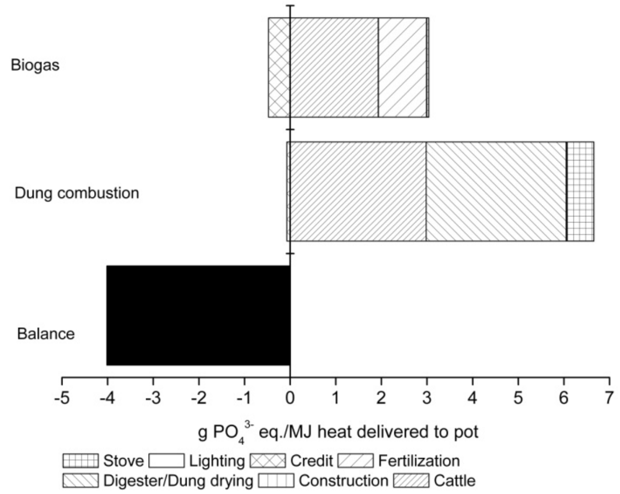

Figure 2: Eutrophication potential

Comparing the performance of the stoves in both systems it becomes clear, that the biogas stove produces much less PO_4^{3-} equivalents compared to the traditional dung stove. The main contributors to the EP caused by the combustion of dung are nitrogen oxides and nitrous oxide. One major reason for this significant difference between the two stove types is the thermal efficiency, which, is fivefold higher for the biogas stove.

Acidification Potential (AP)

The relative shares of the sources contributing to the AP are analogous to the results calculated for the EP. The biogas system thus has 61% less AP emissions compared to the combustion system (Figure 3). The main contributor to the total AP is NH_3, which is responsible for 90.7% in the dung system and nearly 100% in the biogas system. Subsequently, the processes with high NH_3 emissions have a high share at the total AP. An exception is the AP caused by the stoves, which is mainly driven by nitrogen oxides and sulphur dioxide. The main differences between the two systems are the fertilization process from the biogas system, the emissions caused by the stove and the dung drying process in the dung combustion system.

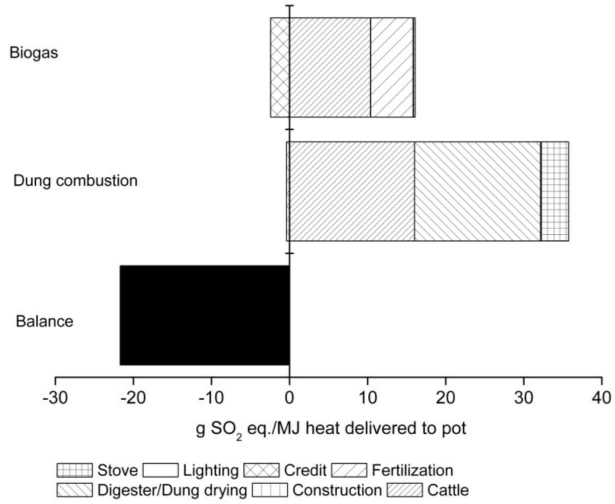

Figure 3: Acidification potential

Human Toxicity Potential (HTP)

The important sources of HTP for this study are the combustion processes taking place directly inside the house. They can give a hint on the health implications of stove and fuel type used. The main substances contributing to the HTP from the combustion processes are nitrogen oxides, non-methane volatile organic compounds (NMVOC) and particle emissions. For the biogas stove, this is only 6% of the emissions caused by dung firing (Figure 4). The dung stove's HTP mainly result from nitrogen oxides (75%), followed by NMVOC (15.9%) and particle emissions (dust) (7.9%). The HTP caused by the biogas stove results with 95.5% mainly from nitrogen oxide, followed by dust (3.5%).

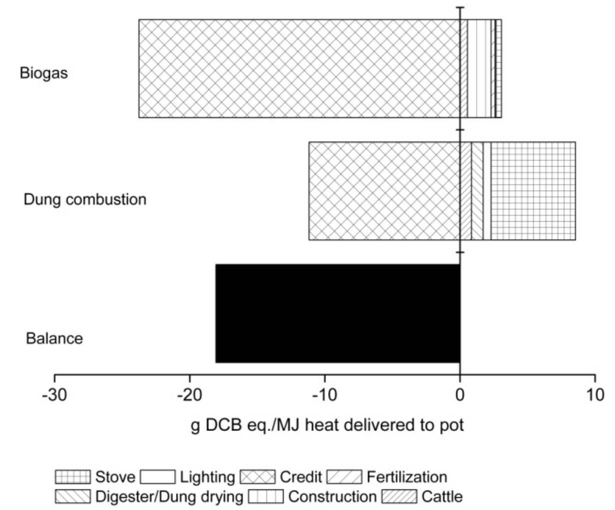

Figure 4: Human toxicity potential

4. CONCLUSION

The results obtained from this study indicate that the provision of thermal household energy by the production and combustion of biogas can contribute to reduce emissions in rural areas of developing countries when dung is used for biogas production instead of burning it as a solid fuel in form of dung cake. A significant amount of GHG emissions can be saved by applying biogas technology. Beside GHG's other emissions can be reduced in the fields of eutrophication, acidification as well as human toxicity. Thereby, the substitution of dung combustion systems is a meaningful way for the improvement of traditional energy systems, especially in respect to global warming and a better healthiness of women and children. Nonetheless, the results can be made more precise by an extensive data collection and measurements in the research area.

5. REFERENCES

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