Tropentag 2011
University of Bonn, October 5 - 7, 2011
Conference on International Research on Food Security, Natural Resource Management and Rural Development

Life Cycle Assessment on the substitution of dung combustion by biogas systems in Ethiopia

Lansche, Jens[1], Steffen Schock[1] and Joachim Müller[1]

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

The utilization of dried dung cakes as a fuel for household cooking stoves is very common in rural areas of Ethiopia. The greenhouse gases thereby emitted contribute to the global warming potential (GWP) and endanger the human health of the local people. In industrialized countries, biogas production by anaerobic digestion is assessed as an efficient way to reduce greenhouse gas emissions from dung management and to preserve nutrients for plant production. The objective of this study was to assess the environmental impacts of biogas systems used for the provision of household energy in rural areas of Ethiopia. Two scenarios for the provision of thermal household energy were taken into consideration. The first one describes the situation at present, where cattle dung is dried and used in household cooking stoves (dung combustion system). The second scenario was the usage of the fresh dung as a substrate for anaerobic digestion to produce biogas and combustion in a biogas stove (biogas system). The method of Life Cycle Assessment was used according to the ISO 14040 and 14044 standards. A model was built with the GaBi-software and a credit approach was used to deal with additional functions of the system. The life cycle inventory was mainly based on literature values e.g. for emissions of dung cake combustion, methane losses of the biogas plants and methane conversion factors. Impact assessment was done using the CML 2001 method in the version of 2007 for the impact categories GWP, acidification potential, eutrophication potential and human toxicity potential (HTP). The production of biogas leads to several environmental advantages compared to the dung combustion system. The results indicate that the GWP can be reduced about 1.36 kg CO_2 equivalents/MJ heat delivered to pot. The fertilizer value is increased due to a higher nitrogen content of the biogas plants effluent compared with the ash of dung combustion. Furthermore, emergence of cooking smoke in households is reduced considerably which results in a saving of 32 g DCB equivalents/MJ heat delivered to pot concerning HTP.

Introduction

Livestock production is an important agricultural as well as economic sector in Ethiopia. An important animal species in this context is cattle with a stock of 51 million heads in 2009 [1]. This is one reason that the utilization of dried cattle dung cakes as fuel for household cooking stoves is very common in rural areas of the country. Several emissions are caused thereby which contribute to global warming, 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) as well as 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 [2]. A study conducted in Gambia had the finding that girls under 5 years, which are raised by mothers cooking, had a six times higher risk of acute respiratory infections than girls raised by smoking parents. Suspended particulate matter and products of incomplete combustion are highly problematic in this respect [3]. These emissions from biomass combustion 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 [4]. But biogas plants in rural Ethiopia are much smaller 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 and less for the provision of household energy. Hence, in respect to their environmental performance, biogas system in Ethiopia can differ significantly from biogas systems in Europe.

Material and Methods

The objective of this study was to assess the environmental impacts for the substitution of dung combustion by biogas systems in rural 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 household 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 [5]. The digesters are fed with cattle dung which is diluted with water. Life cycle inventory was based on literature values e.g. for emissions of dung cake combustion and methane conversion factors and on primary data collected by BARFUSS in field measurements in 2010 [6]. A model was built with the GaBi-software and a credit approach was used to deal with additional functions of the system. 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: 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

Results and Discussion

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 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.

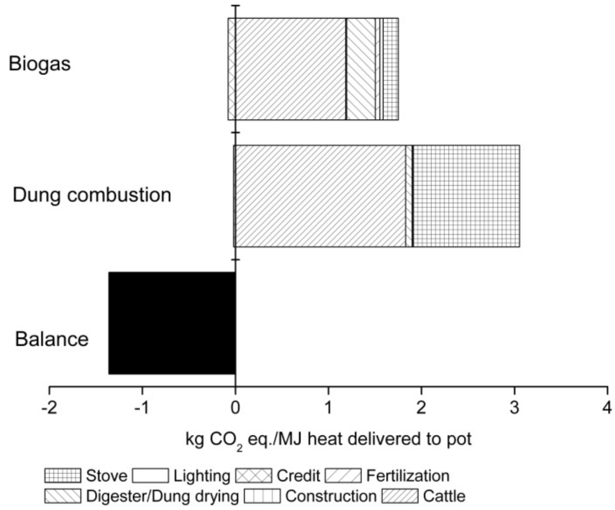

Figure 1: Global warming potential

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. The main influences on GWP are caused by livestock farming and the combustion process in the dung combustion system. Both processes are driven by the combustion efficiency of the stove, the energy content of the fuel and the corresponding fuel consumption. In the biogas scenario CH_4 emissions from the digester are the second largest emission source and therefore show a potential for optimization in respect to the environmental burdens of small-scale biogas production systems.

Eutrophication Potential (EP)

The emissions from livestock farming have a high share on total EP 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 production and transport. Dung drying accounts for 46% of the total EP caused by the dung combustion system. Most of it is caused by NH_3 (98%), followed by N_2O (2%). 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 N_2O. A major reason for this considerable difference between the dung and biogas stoves is the thermal efficiency which is fivefold higher for the biogas stove.

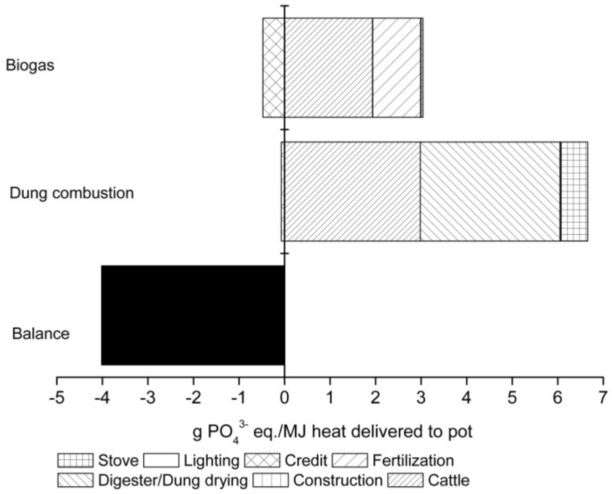

Figure 2: Eutrophication potential

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 91% 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.

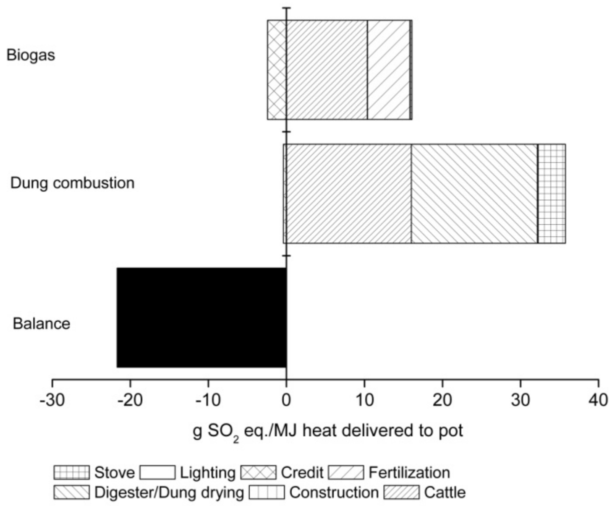

Figure 3: Acidification potential

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 combustion (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%).

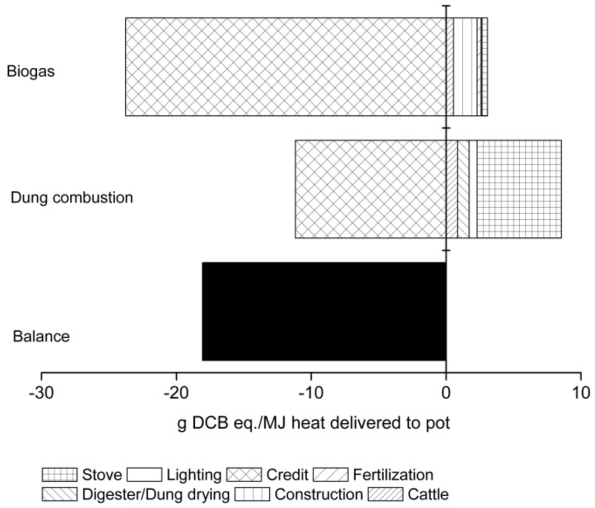

Figure 4: Human toxicity potential

Conclusions and Outlook

The results indicate that a substitution of traditional dung combustion systems by biogas systems in rural Ethiopia leads to environmental advantages. 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 in rural Ethiopia, especially in respect to global warming and a better healthiness of women and children. Nonetheless, literature data of agricultural production or bioenergy systems shows a variation and thereby causes a slight uncertainty in the results. For this reason, further research is necessary to increase the robustness of the results by collection of primary data with extensive measurements in the research area.

References

[1] FAO. "FAO Statistical Yearbook 2010 - Number of animals." Food and Agriculture Organization of the United Nations 2011.

[2] Smith, K. R., Samet, J. M., Romieu, I., Bruce, N., Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax,* 2000, *55*, 518 - 32.

[3] Schwela, D., Cooking smoke: a silent killer. *People Planet,* 1997, *6*, 24 - 25.

[4] Lansche, J., Müller, J., Ökobilanz der Biogaserzeugung auf dem Unteren Lindenhof der Universität Hohenheim. *Landtechnik*, 2011, *3*,

[5] Gwavuya, S. G. "The economics of energy sources in rural Ethiopia," University of Hohenheim 2010.

[6] Barfuss, I., Gwavuya, S., Abele, S., Müller, J. "Improving household energy systems in rural Ethiopia: A comparative study of traditional energy sources and biogas." *Proceedings Tropentag 2011: "Development on the margin"*, Bonn (Germany).