Comparative LCA of Charcoal, Biogas and LPG as Cooking Fuels in Ghana.

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ABSTRACT

According to the Ghana Energy Comission, the non-commercial sector of the country's economy accounts for about 50% of its total energy consumption. During the 2000-2004 period, woodfuels (firewood and charcoal), mainly used for cooking, averaged about 90%, electricity 6.6% and petroleum products 3.2% per annum of the consumption attributed to this sector. While firewood is mainly consumed in the rural areas, charcoal is the dominant cooking fuel in urban areas. Therefore, with the current rapid urbanization, demand for charcoal is expected to rise more than firewood.

Due to the negative effects of the intensive use of woodfuels for cooking, such as deforestation and indoor air pollution, the Ministry of Energy has been promoting the use of Liquefied Petroleum Gas (LPG) as a shift from fuelwood to a more efficient and cleaner burning fuel. Biogas, a renewable gaseous fuel produced from biomass, is becoming increasingly interesting as an alternative to the non-renewable LPG.

This paper presents the results of a comparative environmental analysis of the three cooking fuels- charcoal, biogas and LPG over their life cycles. This is a partial results of an ongoing study to determine the social, cost and environmental implications of cooking fuels in Ghana from a life cycle perspective. The study was conducted following the internationally accepted Life Cycle Assessment (LCA) method in the ISO 14040-14043 series of standards. Data were acquired from company primary documents, questionnaires, field measurements, literature and commercial LCA databases. The functional unit on which the comparison was based is the supply of 1 MJ of useful heat for cooking.

The results show that global warming is the most significant environmental impact associated with the life cycles of the cooking fuels and charcoal makes the largest contribution to this impact (about three times that of LPG, the next major contributor to the impact). LPG shows relatively higher impacts in acidification, entrophication, ozone layer depletion and human toxicity potentials. Direct comparison of the results shows an environmental advantage to biogas in all the investigated impact categories.

Key Words: LCA, cooking fuels, Ghana.

1. INTRODUCTION

According to the Ghana Energy Comission, the non-commercial sector of the country's economy accounts for about 50% of its total energy consumption. During the 2000-2004 period, woodfuels (firewood and charcoal), mainly used for cooking, averaged about 90%, electricity 6.6% and petroleum products 3.2% per annum of the consumption attributed to this sector. While firewood is mainly consumed in the rural areas, charcoal is the dominant cooking fuel in urban areas. About 61% percent of urban households in Ghana use charcoal as their main fuel for cooking [1]. Therefore, with the current rapid urbanization, demand for charcoal is expected to rise more than firewood.

Due to the negative effects of the intensive use of woodfuels for cooking, such as deforestation and indoor air pollution, the Ministry of Energy has been promoting the use of Liquefied Petroleum Gas (LPG) as a shift from fuelwood to a more efficient and cleaner burning fuel [2]. Biogas, a renewable gaseous fuel produced from organic wastes, is becoming increasingly interesting as an alternative to the non-renewable LPG. Several educational institutions and hospitals in Ghana are now producing biogas from their latrines for use as cooking fuels. It is thus clear that Charcoal, LPG and Biogas will constitute a significant share of the household energy consumption in the near future.

With the increasing awareness and concern of the environmental impacts of products and processes, a clear understanding of the environmental impacts associated with a product is needed to help in the promotion of the product. A methodology in use today that helps to measure the total environmental impact across a product's life cycle is the Life Cycle Assessment (LCA). The principal aim of this study was to calculate and compare the main environmental impacts of Charcoal, LPG and Biogas produced in Ghana by using the LCA tool. This is the first phase of an ongoing project to determine the social, cost and environmental implications of cooking fuels in Ghana from a life cycle perspective.

2. METHOD

The study was carried out by means of the standard LCA method developed by the International Organization for Standardization (ISO) in the ISO series 14040 - 14043. The analysis was performed with the help of the LCA software program GaBi 4.

Goal and Scope of Study

The purpose of the study was to conduct environmental life cycle assessments for charcoal, biogas and LPG as cooking fuels and then to compare the results. The study is addressed to people who are interested in the environmental impacts of cooking fuels. Policymakers in the energy and environmental sectors may also find the results useful.

Functional Unit

The functional unit chosen in this study is the supply of 1 MJ useful heat for cooking. This takes into consideration the efficiency of the cookstove used.

System Boundaries

The system boundary defines which processes are included in the analysis.

Biogas: Biogas is produced from the process of anaerobic digestion of wet organic wastes. In this study it was assumed that biogas is produced from animal manure and human faecal matter. The system boundary of the biogas system was drawn around the collection and handling of raw materials, operation of the biogas plant, and use of the biogas produced for cooking. The production of the raw materials is not included in the system boundary as it is more or less a by-product (for example) during the cattle rearing, and not primarily produced for digestion in a biogas plant.

Charcoal: Charcoal is the solid carbon residue following the pyrolysis (carbonization or destructive distillation) of carbonaceous raw materials. In this study wood from natural forest has been selected as the raw material for charcoal production as it is the preferred and most widely used raw material for charcoal production in Ghana. Charcoal production in Ghana is carried out mainly by the informal sector by the use of traditional earth mound method, which is least efficient in terms of charcoal yield [3]. The system boundary for the charcoal system consists of carbonizing the wood to charcoal, transport of charcoal to consumers and cooking with the charcoal. Growing and/or harvesting the wood was excluded from the study, as wood is obtained from natural forests and land clearing activities, and harvesting is mostly done manually without the use of any agricultural machinery.

LPG: LPG is a mixture of propane (C_3H_8), and butane (C_4H_{10}). In Ghana, LPG is produced by the Tema Oil Refinery (TOR). Crude oil, the main raw material for LPG, is imported into the country from Nigeria. For cooking purposes the LPG is filled into steel-cylinders at LPG filling stations. These stations receive the product through road tanker trucks. The system boundary of LPG consists of extraction and transport of crude oil to Ghana, processing in the refinery, product transport to consumers and cooking with LPG.

Data Collection

Data were collected based on the functional unit and the energy values and cookstove efficiencies of the three cooking fuels (Table 1).

Table 1: Energy values and cookstove efficiencies of the various cooking fuels

Cooking fuel	Energy value (kJ/kg)	Cookstove efficiency (%)
Charcoal	25,715	18
Biogas	17,707	55
LPG	45,837	57

[1, 4, 5].

Data on the extraction of crude oil were taken from the Ecoinvent LCA database. Data on the production of LPG were obtained from Tema Oil Refinery (TOR) and the Ecoinvent LCA database. The emissions resulting from the burning of LPG in cookstoves were taken from literature (Jungbluth, 1995; Smith et al, 2000). The life cycle data on biogas were collected through questionnaires, field measurements and other relevant literatures [6, 7, 8]. The data on charcoal had also been collected through questionnaires, field measurements and other relevant literatures [9, 10, 11]. The emissions data resulting from transportation activities were taken from the GaBi 4 LCA software database.

Life Cycle Impact Assessment

The potential human health and environmental impacts associated with the inventory data were determined and analyzed. The following impact assessment categories were considered: Global Warming, Ozone layer depletion, Photochemical ozone creation, Eutrophication, Acidification, and Human toxicity. The impact assessment method chosen to quantify those impact categories is the CML 2001 method.

3. RESULTS AND DISCUSSION

The results of the impact assessment (characterization results) and their analyses are presented in Table 2 and figure 1 respectively.

Table 2: Characterization Results for the life cycles of Biogas, LPG and Charcoal based on the CML 2001 Environmental Impact Assessment Method.

Environmental Impact Category	Biogas	Charcoal	LPG	Unit
Acidification Potential	3.27E-04	7.03E-05	1.24E-02	kg SO_2-equiv.
Eutrophication Potential	1.36E-04	1.25E-05	7.95E-04	kg PO_4^{3-}-equiv
Global Warming Potential (100 years)	3.71E-04	6.31E-01	2.05E-01	kg CO_2-equiv
Human Toxicity Potential	1.33E-04	2.49E-03	8.79E-03	kg DCB-equiv
Ozone Layer Depletion Potential	0.00E+00	7.81E-10	8.02E-07	kg R11-equiv
Photochem. Ozone Creation Potential	4.09E-06	9.34E-03	9.88E-04	kg C_2H_4-equiv

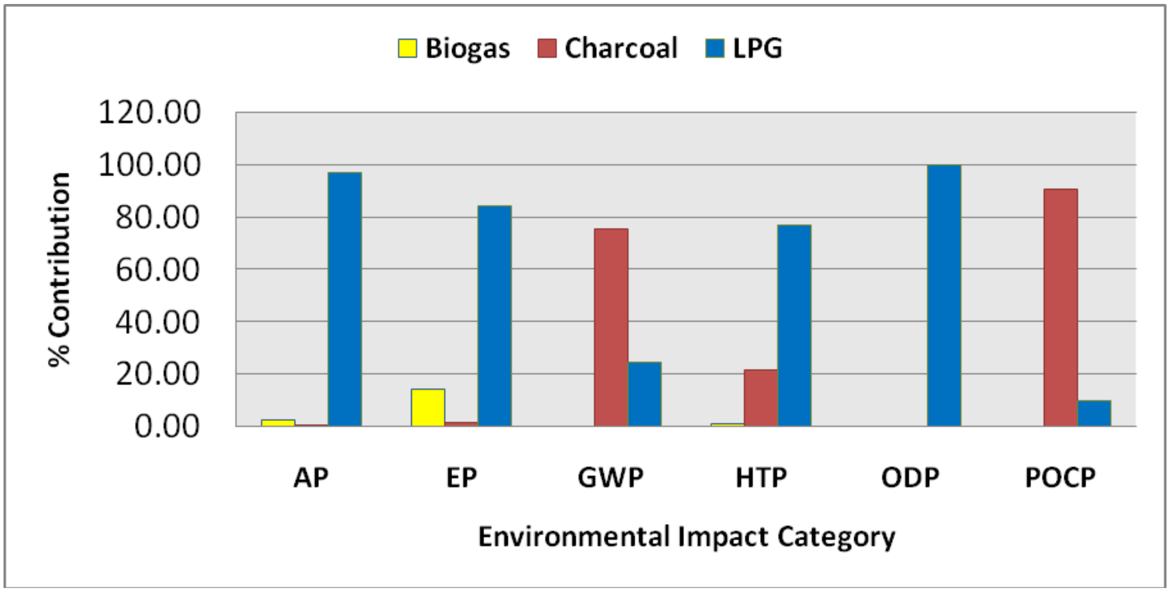

Figure 1: Graph showing percentage contributions by fuel types to impact categories

The results shows that global warming potential is the key environmental impact associated with the life cycles of the cooking fuels studied. It is found that charcoal contributes about 75% to global warming as compared with 24% for LPG and less than 1% for biogas. Thus the contribution of charcoal to the global warming potential is about three times that of LPG. From the analysis of data collected for each life cycle stage of charcoal, it is found that charcoal production stage of the life cycle (kiln emissions) contributed 51% to the global warming impact while the charcoal burning in cookstoves contributed about 47%. Charcoal also made the largest contribution to photochemical ozone creation potential (90.4%).

LPG relatively makes the largest contribution to four out of the six investigated indicators. These are entrophication (84.3%), acidification (97%), ozone layer depletion (99.7%) and human toxicity (77%). This is partly due to upstream production processes (extraction and transport of crude oil over long distance to Ghana).

The direct comparison of results shows an advantage to biogas in all the investigated indicators. Thus biogas may be seen as more environmentally friendly than charcoal and LPG, when used for cooking. The analysis revealed that emissions resulting from the use phase of biogas accounts for about 90% of the life cycle envioronmental impacts of biogas. Thus the production stage of biogas makes no significant negative impact on the environment.

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, an attempt has been made to assess the environmental impacts of three cooking fuels namely, biogas, charcoal and LPG using the LCA tool. The ultimate aim was to provide an environmental information that may help enviornmentally conscious consumers in making cooking fuel choices.

The study has shown that global warming potential is the key environmental impact associated with the life cycles of the cooking fuels studied. Charcoal production and use makes the largest contribution to this impact compared with LPG and biogas. Charcoal is far and away the dominant cooking fuel in urban Ghana. Due to its expected increase in demand because of increasing urbanization, there is the need for a change in consumers' attitudes and behaviour. Consumers must be encouraged to switch to high-efficiency charcoal cookstoves. Charcoal producers must also be trained in modern efficient carbonization processes. Both biogas and LPG being gaseous fuels are considered as clean burning fuels and have been verified by this study as a good way to fight against one of the severe environmental problems of our time - global warming.

This study is still ongoing and it is intended to collect further data and/or perform sensitivity analysis to assess the impacts of changes in inventory data such as improvement in technologies, different feedstocks for biogas other than dung and human faecal matter, and using different charcoal raw materials other than wood from natural forest considered in the present study.

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REFERENCE

[1]. SNEP II (2006): Strategic National Energy Plan 2006-2020. Annex I of IV - Energy Demand Sectors of the Economy. Energy commission, Ghana.

[2]. GHA/UNDP/00051634**:** A Review of the Household Energy Programme for Cooking**.** Energy Commission, Ghana http://www.energycom.gov.gh/household/news., 26/11/2008.

[3]. Gyasi-Nimako, Y. (2003): Prospects for Utilizing Wood Residues for Charcoal Production in Ghana- The Experience of Swiss Lumber Co. Expert Consultation on Wood Residue Utilization for Energy Generation in Ghana. Organized by Tropenbos International, Ghana. Paper delivered at conference room of Forestry Research Institute of Ghana (FORIG), August 11, 2003.

[4]. Smith K. R., Uma R., Kishore V.V.N., et al (2000): Greenhouse Gases from Small-Scale Combustion Devices In Developing Countries Phase IIa- Household Stoves in India. Prepared for: U.S.

Environmental Protection Agency Office of Research and Development, Washington, DC. EPA/600/R-00/052.

[5]. Jungbluth, N. (1995): Restricted Life Cycle Assessment for the Use of Liquefied Petroleum Gas and Kerosene as Cooking Fuels in India. A master's thesis report submitted to the Technical University of Berlin, Germany.

[6]. Auer, S. (2006): Ethanol vs. biogas used as car fuels. Institute of Environmental Strategies Research (KTH), Sweden.

[7]. Berglund, M. (2006): Biogas Production from a Systems' Analytical Perspective. LTH.

[8]. Marchaim, U. (1992): Biogas processes for sustainable development. FAO technical paper. Retrieved from http://www.fao.org/docrep/T0541E/T0541E00.

[9]. Kammen, D. M., & Debra, J. L. (2005): Review of Technologies for the Production and Use of Charcoal - Renewable and Appropriate Energy Laboratory Report. Energy and Resources Group & Goldman School of Public Policy University of California, Berkeley.

[10]. Lacaux, J. P., Brocard, D., Lacaux, C., Delmas, R., Brou, A., Yoboué, V. and Koffi, M. (1994): Traditional charcoal making: an important source of atmospheric pollution in the African tropics. Atmospheric Research, 35 (1), 71.

[11]. Smith, K. R. and Thorneloe, S. A. (1992): Household Fuels in Developing Countries: Global Warming, Health and Energy Implications. U. S. EPA Working Paper.