Analysis of the life-cycle costs and environmental impacts of cooking fuels used in Ghana.

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Abstract: The life-cycle approach has currently become one of the most actively utilised techniques for the study and analysis of strategies for environmental sustainability. While the approach started with an analysis solely of environmental loads and their impacts, the integration of environment and economic analyses as a basis for decisions-making is receiving increasing attention. This study evaluated the costs and life-cycle environmental impacts of energy used in Ghanaian households for the purpose of cooking. The analysis covered all the common cooking energy sources (firewood, charcoal, biogas, kerosene, liquefied petroleum gas, and electricity). The choice of fuel to meet both environmental and costs demands is not straighfoward. The findings of the study as well as discussions on meeting the demand for energy for cooking in an affordable and sustainable fashion are presented.

1 Introduction

Most of the effects of the use of fossil fuels on the global environment are well-known and have been documented in many scientific studies in the literature. Developed countries, because of their extensive need for energy, are the most to blame for the adverse effects of the use of these fuels, such as acidification, global warming and ozone-depletion. Not as much attention seems to have been given to the fact that less-developed countries, less dependent on fossil fuels because of the costs associated with them and their need for less energy generally, have insidiously become major contributors to the global environmental degradation while trying to satisfy one of the basic needs of man: the need for cooked food [1-3]. In developing countries, where laws are not properly enforced, forests are indiscriminately cleared for the economic sustenance of the rural dwellers, but in the process an important sink for carbon dioxide removal from the atmosphere is decimated. In addition, the fuels produced directly from the forest can also contribute significantly to some of the global environmental problems such as global warming [4-6]. Thus the production and use of fuels for cooking in developing countries deserve more serious attention than has hitherto been given.

In Ghana estimates show that woodfuels, mainly firewood and charcoal, used for household cooking, account for the largest percentage (over 60%), of the total national energy consumption and constitute 2% of the Gross Domestic Product [7]. The Housing and Population Census of Ghana 2000, gave the breakdown of the fuels used for cooking by households as follows: firewood (53.8%), charcoal (28.9%), crop residues (7.4%), LPG (5.9%), kerosene (2.9%) and electricity (1.1%) [8]. Currently biogas is also being promoted as another renewable source, but this has met with limited success, except in bio-sanitation usage in a few schools, slaughterhouses and hospitals [7].

Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are tools used to make a cradle-to-grave analysis of the environmental and economic consequences of using products or providing services [9]. An earlier study by the authors examined the environmental impacts of three of the locally available cooking fuels namely, biogas, charcoal and LPG [10]. The current study seeks to extend the analysis to the three remaining cooking fuel sources namely firewood, kerosene and electricity, and to examine the lifetime costs associated with all the local fuels.

Whilst there is an internationally standardized method for conducting LCA in the ISO 14040-14043 series, LCC does not yet have an agreed framework or methods of conduct. A guideline (LCA type) for LCC is being developed by SETAC as a basis for future standardization [11]. Conventionally, life-cycle costs are calculated by summing all the costs associated with the initial purchase, installation, operation and maintenance of a system throughout its operational lifetime. When comparing technically equivalent alternatives, the time period normally chosen for comparison is the lifetime of the longest-surviving system or component among the group being studied [12].

2 Method

The LCA aspect of the study was carried out using the standard LCA guidelines developed by the International Organization for Standardization (ISO) in their ISO 14040-14043 series. Although various life-cycle cost analysis approaches are now available in the literature [11-14], they have not gained the universal acceptance that the pure LCA methodology has. In this work the life-cycle costs of the cooking fuels and their corresponding cookstoves were determined by surveying the market for their prices.

2.1 LCA of firewood, kerosene and electricity as cooking fuels

2.1.1 Goal and scope of the LCA study

The goal of the current LCA study was to determine the life-cycle environmental impacts of firewood, kerosene and electricity, which are used as cooking fuels in Ghana, and to add the results to that of an earlier study by the authors, in which the same study was done with biogas, charcoal and LPG. This is meant to provide a complete assessment of the environmental impacts of all the major fuels used for cooking in the country. Although the focus of the study was Ghana, it was not possible to find all the needed information locally and therefore, as is normally done in LCA studies, results of similar studies conducted in other developing countries were substituted, where necessary. In this study - as in the previous one - a functional unit of 1MJ of energy delivered to the cooking pot, was used as basis for the analysis.

2.1.2 Assumptions and limitations of the LCA study

Firewood: Ninety percent of woodfuels used in Ghana are obtained directly from the natural forest. The remaining 10 percent are from wood waste, such as logging and sawmill residues, and planted forests. (Ghana exports charcoal and the law requires that companies engaged in this operation plant the trees they use as source for their exports.) In this study, it is assumed that the firewood used for cooking, which is normally deadwood or branches broken from live trees, is collected from farms and neighbouring forests, usually by women and children. Transporting the firewood has not been taken into account since it is normally carried home by human beings. Thus no environmental impacts were assigned to firewood production and transportation. It is also assumed that cooking is done on the traditional three-point mud-stove that is commonly available in Ghanaian rural households.

Electricity: Hydropower constitutes about 70% of Ghana's grid electricity supply and hence electricity obtained from this source was assumed for the study. No data is available on the energy and material inputs involved during the construction of the hydroelectric power plants. It was also difficult to obtain relevant environmental data on the operations of the existing plants. Hence standard LCA databases were used to estimate the impacts of electricity production from these plants. Environmental burdens associated with the transmission and distribution of power from the centralized grid, including the manufacturing of poles and cables, were also not included due to lack of relevant data.

Kerosene: In Ghana kerosene is produced by the Tema Oil Refinery, the only one in thecountry. Crude oil, the raw material used for kerosene production, is imported from Nigeria. Data on both upstream and downstream processes are required. The upstream processes include crude oil exploration, production, and transportation to Ghana, while the downstream processes involve refining the oil into kerosene and other by-products at the refinery. Data on both upstream and downstream production processes were taken from the Ecoinvent database. The data from the database also take into account inputs and outputs for the construction, maintenance and operation of the production equipments. The final product, kerosene, is first transported to filling stations scattered across the country. An average transporting distance of 250 km was used for kerosene, as the product is used for cooking mainly in the urban areas, most of whom are located in the southern part of the country not too far from the refinery. Finally, LCI data covering the manufacture of the cookstoves for all the fuels have not been included due to non-availability of data.

2.1.3 Life cycle inventory data collection

Inventory data on crude oil extraction and refining to produce kerosene and other petroleum products, as well as electricity production from hydropower plant were taken from the Ecoinvent LCA database. Emission factors due to the transportation of kerosene from the refinery to consumer filling stations were taken from the GaBi 4 LCA database. The emissions resulting from the burning of kerosene and firewood in cookstoves (Tab. 1) came from the work of Jungbluth [1, 14]. Cooking with electricity does not cause any direct emissions [1].

Tab.1: Inventory data for cookstove emissions (kg/MJ fuel)

Emission/fuel	Kerosene	Firewood
NOx	7.17E-05	1.00E-04
PM	9.00E-06	3.00E-04
CO	5.73E-04	8.00E-03
CH4	1.15E-05	5.00E-04
NMVOC	1.43E-04	3.00E-03
N2O	1.00E-06	1.00E-05
SO2	9.30E-05	2.10E-05
CO2	7.34E-02	9.59E-02

Adapted from [1, 14].

2.1.4 Life cycle impact assessment

The potential human health and environmental impacts associated with the inventory data were determined and analyzed using the CML 2001 impact assessment method with the help of the GaBi 4 LCA software.

2.2 Calculation of life cycle costs of cooking fuels

The life cycle costs for the various fuels were calculated using the conventional approach, that is by summing the capital costs for the cooking stage, replacement and annual costs of fuels over a chosen period of ten years.

2.2.1 Data collection for life-cycle costs

The market prices of the various components were obtained from direct and indirect sources like field/market survey, reports and expert opinions. Due to the unavailability of fuel production equipment procurement and installation costs, these portions of the capital cost were not included in the analysis. Tab. 2 gives the initial capital and replacement costs of the appliances required for cooking, while Tab. 3 gives the annual costs of fuel consumption.

Tab.2: Costs of cooking appliances (based on 10 years analysis period)

Fuel	Cooking appliance	Cost of appl. (US$)	Life time (yrs)	Replacement frequency	Replacement Cost (US$)
Firewood	3-stone mud stove	0	3	3 times	0
Charcoal	Improved stove	10.34	5	1 time	10.34
Kerosene	(1-2) burner stove	20.69	3	1 time	20.69
LPG	(1-2) burner stove	25.00	5	1 time	25.00
	Gas storage vessel	41.38	10	none	None
Electricity	(1-2) burner stove	34.48	5	1 time	34.48
Biogas	(1-2) burner stove	48.28	5	1 time	48.28

Tab.3: Annual cost of cooking fuels consumption (2005)

Fuel	Stove Eff. (%)	Calorific Value (kWh/kg)	Consump/HHD (kWh/yr)*	Cost of fuel (US cents/kWh)*	Cost of fuel consump/HHD/yr (US $/kWh)
Firewood	14	3.9	7,143	1.2	85.72
Charcoal	18	8.5	5,556	1.9	105.56
Kerosene	35	12.7	2,857	6.6	188.56
LPG	45	13.0	2,222	5.5	122.21
Electricity	65	1.0	1,538	7.3	112.27
Biogas	55	6.7	-	-	80.00**

* Source: [15]; ** estimated; Avg. size of household = 4.3

2.2.2 Life cycle cost calculation

The life-cycle costs were calculated by summing costs of cooking appliances, replacement costs and annual fuel consumption costs discounted at 10% interest rate using the relation

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

where: $p = \text{present worth}$, $A = \text{amount}$, $i = \text{interest rate}: 10\%$

$n = \text{number of interest periods}: 10$

3 Results and Discussions

3.1 Results of life cycle impact assessment

The results of the impact assessment for firewood, kerosene and electricity are included with those from the earlier studies by the authors in Tab. 4. A graph showing the relative contribution of each fuel system to the impact categories is also shown in Fig. 1.

Tab.4: Quantified environmental profile of cooking fuel systems (characterization results) based on the CML 2001 environmental impact assessment method.

Impact Category	Biogas*	Charcoal*	LPG*	Firewood	Kerosene	Electricity	unit
AP	2.57E-05	1.68E-04	2.25E-05	9.80E-05	1.98E-04	1.47E-05	kg SO2
EP	1.19E-06	3.02E-05	1.40E+00	1.43E-05	3.00E-01	2.78E-06	kg PO43-
FAETP	3.02E-06	1.13E-03	4.95E-02	4.46E-05	3.01E-02	7.15E-04	kg DCB
GWP	1.63E-01	1.45E+00	1.20E-01	1.56E-01	8.16E-02	4.43E-03	kg CO2
HTP	1.68E-05	1.64E-03	3.71E+01	1.87E-04	1.50E+01	2.33E-03	kg DCB
POCP	3.22E-05	1.19E-02	2.83E-04	5.63E-04	8.80E-05	1.87E-06	kg C2H4
TETP	3.44E-07	1.29E-04	2.13E+00	5.08E-06	1.00E+00	8.54E-05	kg DCB

* Source: [10].

AP = Acidification Potential; EP = Eutrophication Potential; FAETP = Freshwater Aquatic Ecotoxicity Potential; GWP = Global Warming Potential; HTP = Human Toxicity Potential; POCP = Photochemical Ozone Creation Potential; TETP = Terrestial Ecotoxicity Potential; DCB = 1,4-dichlorobenzene.

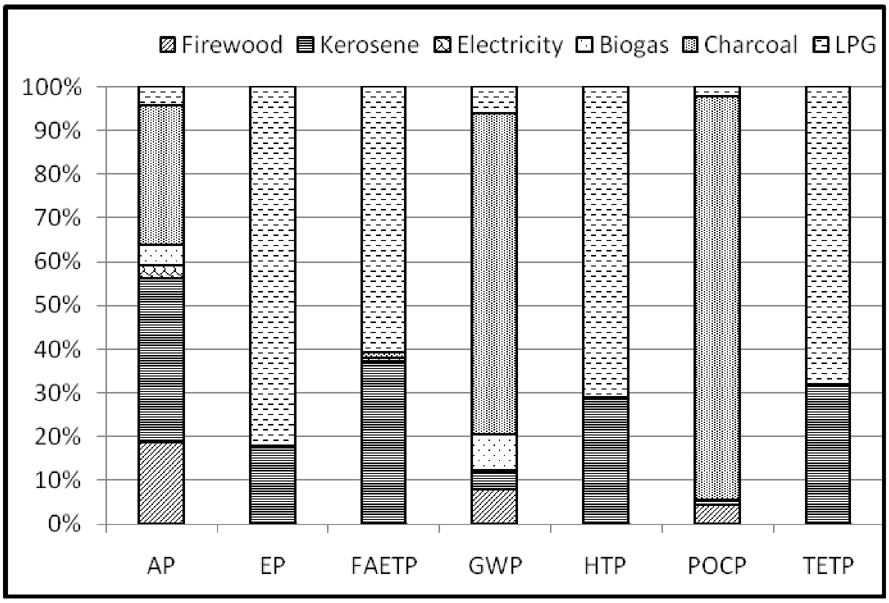

Fig.1: Percentage contribution of cooking fuel systems to selected environmental impact categories

Fig. 1 shows that firewood contributes 18.58% to AP, 7.88% to GWP and 4.37% to POCP and negligibly to the other impacts. Charcoal contributes significantly to AP (31.93%), GWP (73.45%) and POCP (92.49%). Kerosene and LPG make more contributions to five out of the seven selected impact categories. Biogas and electricity were found to make the least impacts to selected impact categories.

A comparison of the impact assessment results shows an advantage to biogas and electricity usage in nearly all the investigated indicators. It must be noted that electric stoves are reported to emit no emissions and hence no environmental impacts were attributed to the cooking stage of electricity. The low impact scores for electricity could also be due to the non-inclusion of the impacts of hydropower dam construction. The construction of hydro dams for electricity generation in general can extensively interefere with the environment. The amount of building materials used and their source, also accounts for some environmental impacts. However, these impacts are difficult to quantify, especially many years after the construction of such structures. Also the transmission of electricty from the centralized grid to all parts of the country impacts negatively on the environment. The manufacture of transmission cables and poles, use of herbicides to prevent trees from growing near the lines, etc., are all important factors, but were not included due to lack of data.

All the environmental impacts of firewood were attributed to the cooking stage only, as those from the production and transportations stages were considered to be negligible. It must be noted that in addition to the traditional agricultural practice of land-clearing for new farms the over-exploitation of woodfuel also contributes significantly to the deforestation and degradation of forest resources. These activities can potentially have serious economic impacts, in addition to the environmental effects, on a large number of people in the future.

A major concern has been the direct impact of cookstoves emissions on women and children. In terms of cookstove emissions, the study shows that firewood emit the most gaseous pollutants followed charcoal, biogas, kerosene, LPG and electricity. For most households where woodfuel use is expected to increase, using charcoal instead of firewood could improve health since the direct exposure to cookstove emissions is less for charcoal than for firewood. Most of the emissions associated with charcoal originate from the production and not the cooking stage. Tab. 3 also shows that less fuel is required for cooking with electric and LPG stoves due to the high efficiency of the stoves.

The inventory data taken from LCA databases for kerosene and LPG production takes into consideration the impacts from crude oil extraction and construction of refinery plant. These contributed significantly to LPG and kerosene’s higher scores in most of the impacts categories.

3.2 Results of life cycle cost calculation

Tab. 5 gives the life-cyle costs of the cooking fuel systems based on the conventional approach. Not surprisingly firewood is the cheapest among the fuels. In the urban areas, the cost of firewood production is mainly in the transportation, since most people fetch them free-of-charge from neighbouring forest. The table clearly shows that the shift from firewood to kerosene would be the worst option, as far as cost is concerned. For the majority of firewood users who earn less than US$2 a day, this would not be possible.

Due to the obvious deleterious effect of using firewood and charcoal on human health and on the environment, however, government has sought to replace the use of these fuels with LPG. The cost implications, both on the part of the users and also on the government, in terms of subsidies, have not made this option possible either. Estimates by the Energy Commission of Ghana also indicate that the demand of LPG, if it were to replace charcoal and firewood would be such that it could not be met [7].

Tab.5: Results of life cycle cost calculations

Item	Charcoal	Biogas	LPG	Firewood	Kerosene	Electricity
Analysis period	10 years	10 years	10 years	10 years	10 years	10 years
Cost of cooking appliances (USD)	10.34	48.28	111.38	0.00	20.69	34.48
Replacement cost (USD)	10.34	48.28	25.00	0.00	20.69	34.48
Annual fuel cost (USD)	105.56	80.00	750.98	85.72	188.56	112.27
Discount rate	10%	10%	10%	10%	10%	10%
Residual costs (USD)	0	0	0	0	0	0
Life cycle cost (USD)	669.35`	588.16	862.36	526.75	1,200.08	758.86

Taking both health and costs concerns into consideration therefore, an obvious option may be to first promote a shift from firewood to charcoal. However, for every unit of charcoal produced, 4-6 units of wood are consumed, and moreover charcoal generates more greenhouse gases (methane) than firewood [7]. Therefore this shift may not be a such a viable option, in terms of attracting CDM projects.

4 Conclusion

Meeting the demand for energy for cooking in an affordable and sustainable fashion will require a combination of factors and sources. The solution lies in improvement of the renewable sources of energy production by promoting energy forest cultivation, improving design of stoves, improving the construction of stoves and kilns, and promoting the use of biogas, which has not yet caught on significantly in the country. Skilled personnnel need to be trained to deliver these services effectively.

Further work will involve the conduct of sensitivity and uncertainty analyses on the costs and environmental impacts associated with the various fuels. The life-cycle costs of LPG, kerosene and electricity could also be significantly affected when capital and installation costs of fuel production equipment are considered in subsequent work. Their production facilities and processes involve large-scale capital-intensive components, compared to the family, small-scale facilities used for biogas and charcoal production. Reliance on international database could be reduced with more locally acquired data.

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