Arbeitsgemeinschaft
Tropische und Subtropische Agrarforschung (ATSAF) e.V.

Council for Tropical and Subtropical Agricultural Research

ATSAF - CGIAR++ Junior Scientists Program
Final Report

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Start and end date of stay at IARC: 27 Sep 2018 - 10 Apr 2019
Start and end date of remotely supervised project: -
Title: Cost-benefit analysis of faecal sludge-based briquettes and biogas and value chain analysis for adoption at large scale

Funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

International Water Management Institute (IWMI)

Ghana

INTERNSHIP REPORT

Cost-benefit analysis of faecal sludge-based briquettes and biogas and value chain analysis for adoption at large scale

Moudachirou Lamidi

April 2019

Acknowledgement

This internship decision aims at contributing to find appropriate solutions to the sanitation challenges facing developing countries. It was a quite challenging journey that would not be possible without the support of several people and institutions.

First of all, I would like to address my sincere acknowledgement to my academic Supervisor, Professor Christian Lippert, who gave me his support from the beginning of this endeavour. Thank you very much for your guidance.

Secondly, I would like to express my gratitude to the Arbeitsgemeinschaft für Arbeitsgemeinschaft Tropische und Subtropische Agrarforschung for their funding without which this internship in Ghana would not be possible. A special thank to Ms Sarah Glatzle, our contact person, for her diligence before my departure to Ghana.

Thirdly, I would like to thank the International Water Management Institute (IWMI) for hosting me and for the warm welcome at the Institute. Thank you to all the employees of IWMI for accepting me as part of their family without condition and for helping me out during my stay in Ghana. I would also like to express my sincere gratitude to my Supervisor at the Institute, Dr Solomie A. Gebrezgabher, for her support and guidance during the internship.

Finally, I would like to extend my acknowledgement to the different informants, in particular, Safi Sana, Waste Management Department of the Accra Metropolitan Assembly, BTAL, Energy Commission of Ghana, public toilet managers. For all those whose names have been omitted, receive my sincere gratitude.

Context

Sanitation in general and Faecal Sludge Management (FSM) in particular is a serious issue in the developing countries (Peal et al., 2014a). In 2015, about 2.3 billion people mostly living in low-and-middle-income countries do not have access to even basic sanitation services (WHO/UNICEF, 2017) from which about one billion live in cities (Strande, 2014). With a fast-growing population, the urbanization and the rural-urban migration, the demand for FSM services is also increasing by manifolds. This led to a big discrepancy between the development of sanitation facilities and population growth, particularly in big cities (Agyei et al., 2011; Cofie et al., 2009; Peal et al., 2014b).

Ghana in Sub-Saharan Africa is one of the fast-growing countries with a GDP growth rate of 7.9 % on average in 2017 (Embassy of The Kingdom of The Netherlands - Accra, 2018) and 53 % urbanisation rate in 2014 (Mansour et al., 2017). However, Ghana does not stand out in the region in terms of sanitation. Ghana also is characterised by limited access to sanitation services throughout the country. The lack of appropriate FSM facilities in the major cities is detrimental to public health (Cofie et al., 2009). The sewerage system is only available in three cities – Kumasi, Accra, and Tema – and only serves a small share of the population; the majority of the households still rely on on-site sanitation systems (OSS) and public toilets (Mansour et al., 2017). Murray & al. (2011) reported that only 10% of the faecal sludge is appropriately treated in the whole country; the situation in rural areas is overlooked.

The untreated faecal sludge is disposed of or dumped into the environment (water streams, landfills) in the outskirts of the cities or even used as organic fertiliser in certain regions due to limited reuse options and/or disposal facilities (Appiah-Effah, 2016; Jiménez et al., 2010). In Accra for instance, 72 % of untreated faecal sludge is dumped into the sea (Mansour et al., 2017). These practices present a lot of health and environmental hazards. In fact, the use of untreated faecal sludge as landfills and in agriculture presents many risks due to leachate, the presence of heavy metals (zinc, chromium, nickel, lead, tin, copper, etc.) (Samolada & Zabaniotou, 2014) and biological traits (viruses, bacteria, fungi, and protozoa) (O. Cofie et al., 2009) which can get into the food chain and/or pollute the environment (World Bank, 2013). Most water-borne diseases like diarrhoea, cholera, typhoid fever are attributed to the mismanagement of faecal sludge (Rose, Parker, Jefferson, & Cartmell, 2015; Snel & Smet, 2006; UNICEF Ghana, 2015).

On the other hand, in Ghana, over 70% and 50 % of the rural and urban households respectively depend on fuelwood (firewood and charcoal) for cooking and heating (Energy Commission of Ghana, 2017). Agricultural production practices combined with households' dependency on fuelwood have exacerbated the pressure on natural resources. The forestry commission of Ghana estimated the annual forest area loss to 3.5 % starting from 2001 (Forestry Commission, 2017). The commission pointed out fuelwood though marginal as one of the causes of deforestation in Ghana. Fuelwood utilisation has a double impact on carbon emission. It not only reduces forests' potential to sequestrate carbon dioxide but also releases the already sequestrated carbon back into the atmosphere. The need for alternative clean energies for cooking and heating is therefore vital to subjugate environmental degradation. The double burden of sanitation and environmental problems need to be solved.

Problem statement and justification

To achieve the 6th Sustainable Development Goals (SDGs) on water and sanitation, lots of effort and resources have been deployed by governments and different partners across the low-and-middle-income countries to provide households with potable water particularly in rural areas. Most focus has been put on clean water provision and sanitation has faded into the background. However, as part of the project zero open-defecation by 2022 initiated by the WHO/UNICEF, many OSS have been constructed. The Government of Ghana, to tackle the problem in Accra, has passed a law to prevent open defecation in the capital city. Moreover, several public toilets have been constructed in slum areas as ancillary measures. This deed is explained by the inability of the households to afford the costs of construction of VIP or the inadequacy of the settlements for that purpose. The slum areas are in fact unplanned settlements characterised by congested alleys and inaccessible to vacuum truck to operate.

Unfortunately, there are no ancillary measures to properly handle the subsequent problem created by the provision of OSS to the populations. The volume of faecal sludge produced is very large and outweighs the capacity of the still functioning treatment plants. In fact, out of 17 faecal sludge treatment facilities in Ghana, only 3 are fully functional fun. As a result, about 90 % of the faecal sludge is disposed of raw or partially treated in nature (Murray & al., 2011). This also is due to the inherent problem of collection and long-haulage distances, the limited disposal facilities (Strauss & Montangero, 2004). The provision of OSS is not any more sustainable and it is vital that all the stakeholders come together to tackle the problem.

The private sector is reluctant to step into this business because of the high costs of collection and haulage (Boot & Scott, 2008). Furthermore, faecal sludge is treated as a waste to be disposed of in most cases and the provision of sanitation services do not generate much return (Gold et al., 2014). Consequently, most of the faecal sludge collected ends dumped into the environment or the sea. This practices often backfire with frequent outbreaks of water-borne diseases putting the public health at risk. The lack of disposal facilities or treatment plants also leads to the utilisation, in certain regions, of raw faecal sludge to fertilise agricultural lands (Cofie et al., 2005).

The recent paradigm shift and the development of circular economy around the world has foster recycling and materials reuse. Faecal sludge like any other resources must be given "*a second life*" to close the nutrient loop. It is, therefore, necessary to develop business models around this valuable resource as a way to attract the private sector to invest in sanitation service provision. Fortunately, many studies (Diener et al., 2014; Otoo et al., 2016; Semiyaga et al., 2015) carried out in low-and-middle-income countries on possible business models within the sanitation value chain reveal that there are lots of potentials to tap to overcome the sanitation challenges. Several faecal sludge based (FS-based) technologies (compost, briquettes, pellets, biogas and biochar) have been identified as sound solutions to tackle both health and environmental risks and generate revenues.

Nonetheless, compost and co-compost are the most prevalent FS-based sub-products in low-and-middle-income countries (Gold et al., 2014). This may be due to the fact that agriculture is the mainstay of their economy or because of the limited technological capabilities and the infrastructures for faecal sludge management.

This study aims at filling up this gap by providing a thorough socio-economic assessment of alternatives FS-based technologies like briquettes and biogas for households cooking and heating. This will help to address the sanitation and forest degradation challenges. It also will provide decision-makers with broad manoeuvring capabilities for choosing the best technology available for not all technologies are suitable for all communities (Semiyaga et al., 2015). An analysis of the FS value chain is, therefore, necessary to determine the bottlenecks for the adoption at large scale of the FS-based briquettes and biochar. What are the impacts of the FS-based technologies and the bottlenecks for their adoption at a large scale?

Study objectives

The main objective of this research is to assess the economic, social and environmental impacts of FS-based briquettes and biogas in Greater Accra.

In a specific way, we will:

1. evaluate the socio-economic impact of FS-based briquettes and biogas;
    - ❖ identify indicators for assessing the economic, social and environmental impacts;
    - ❖ quantify the economic, social and environmental indicators and determine the overall socio-economic impact;
2. and identify the bottlenecks for the adoption of FS-based technologies at large scale.

The following questions will guide this research:

- what are the indicators for assessing the socio-economic and environmental impacts of FS-based briquettes and biogas?
- are the overall benefits of FS-based briquettes and biogas production outweigh the costs?
- what are the bottlenecks for the adoption of faecal sludge based technologies at large scale?

Methodology

This is a desk study and this section presents the modus operandi of the research.

Data collection

Two categories of data have been collected: secondary and primary data.

The primary data have been collected through interviews with different stakeholders of the FS value chain. I have interviewed two public toilet managers, the liquid and solid waste management officers of the Accra Metropolitan Assembly, the manager of a biogas production factory called SAFI SANA, the Director of the Biogas Technologies Africa Limited (BTAL), and an officer of the Energy commission Ghana. Unfortunately, I could not interview the officer in charge of Household Air Pollution of the Accra Health service. I could not make contact with private waste management companies. All the attempts to meet the managers have been vain. I also collected the price of charcoal, wood, LPG, gas bottle and the price of different machines and equipment.

The secondary data have been collected through an extensive literature review on the topic and related topics. For that purpose, different books, peer-reviewed articles, institutions reports and proceedings have been used. To retrieve appropriate data, I consulted periodical reports of the IPCC, IEA, WHO and different Ghanaian institutions like the Energy Commission, the Forestry Commission, the Bank of Ghana (for data on the discount rate and the escalation of prices), etc. It is also necessary to mention that I put a particular accent on peer review articles/journals.

Data analysis

Two excel files have been used for data processing and analysis; one file for briquettes and the other for biogas. Each excel file contains mainly 4 sheets: content, input for the baseline scenario, input under the alternative scenario and a sheet for the socioeconomic analysis. The different scenarios are presented in table n° 1.

Table n° 1: description of the baseline and alternative scenarios

Technologies	**Baselines scenario**	**Alternative scenarios**
All technologies	• Dumping of raw or semi-treated faecal sludge into the environment, open defecation • Municipal solid wastes are also dumped without any system to collect biogas	Utilisation of faecal sludge and municipal solid wastes to produce briquettes and biogas
Briquettes	Households, institutions and small businesses (bakers, fish smokers, etc.) use fuelwood /charcoal for cooking and heating	Shift from fuelwood and charcoal utilisation to FS-based briquettes for cooking and heating
Biogas	Households, institutions and small businesses (bakers, fish smokers, etc.) use fuelwood /charcoal for cooking	Shift from fuelwood and charcoal utilisation to FS-based biogas for cooking

Source: author

Under the baseline scenario, faecal sludge collected from public toilets and private onsite sanitation facilities is dumped into the environment untreated or partially treated and then dumped into the environment. Moreover, households, institutions (bakers, fish smokers, etc.) and small businesses use wood and charcoal for cooking and heating purposes.

Under the alternative scenario, there is better management of faecal sludge and municipal solid wastes which are turned into energy (briquettes and biochar). Then households, institutions and small businesses (bakers, fish smokers, etc.) shift from the utilisation of wood and charcoal for cooking and heating to the utilisation of FS-based briquettes and biogas.

The socio-economic analysis has been performed using the cost-benefit analysis. The conceptual framework is presented in figure n°1.

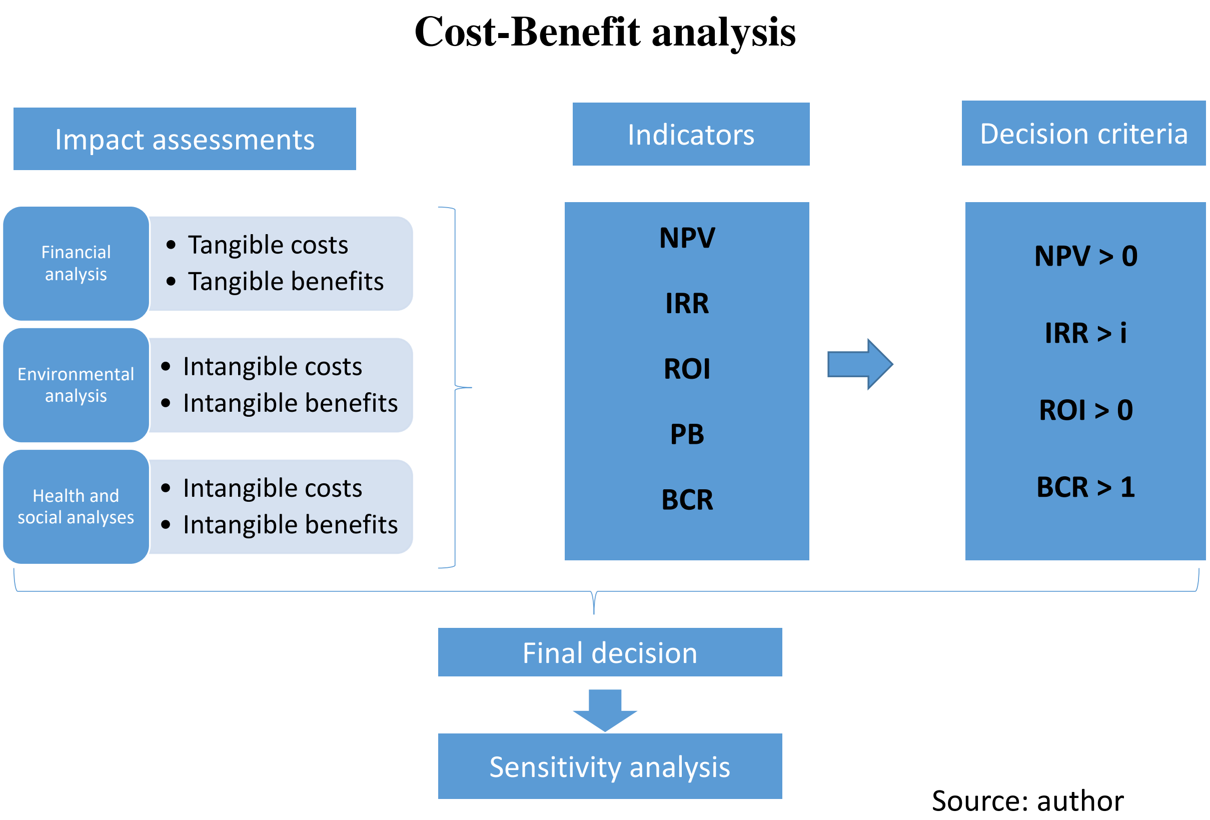

Figure n° 1: Cost-benefit analysis conceptual framework

The Cost-Benefit Analysis (CBA) is a scientific framework or method which helps in decision-making. The principle of CBA is to calculate the Net Present Value based on a stream of costs and benefits over the lifetime of the project. The CBA is appropriate for this study because faecal sludge management is associated with environmental costs and benefits, which costs and benefits are usually not included in the financial appraisal. They also induce a market failure since public health is at stake.

- Financial analysis takes into account tangible costs and benefits i.e. investment costs, production and running costs, different taxes and the revenue from the sale of the by-products.
- Environmental assessment assesses the environmental cost and benefits. These are called intangible costs and benefits because it is difficult to put a price tag on environmental goods. As environmental costs, we have, for instance, the emission of GHG due to the utilisation of fuelwood and the production of briquettes and the environmental benefits are seen in terms of emission saving or avoided due to the shift to briquettes utilisation.
- Social impact assessment like the environmental costs and benefits are intangible costs and benefits. We have for instance job created, the cost of treatment of FS related diseases avoided. Tools like DALYs are used to assess health impacts but they have not been used in the framework of this study. Household Air Pollution (HAP) is responsible for millions of deaths per year and are attributed to the use of woodfuel for cooking and heating. However, the number of deaths due to fuelwood utilisation is difficult to determine. Thus, health impacts are not included in the socioeconomic analysis.

The final decision regarding the project is taken based on the "decision criteria". When the project is feasible, a sensitivity analysis is performed. The sensitivity analysis is a method used to check the robustness of the socioeconomic results. Some important parameters like the discount rate, the investment cost, the prices of the feedstocks and the final product are varied to identify the threshold of the feasibility of the project.

Description of the International Water Management Institute (IWMI)

The International Water Management Institute (IWMI) is a non-profit, scientific research organization focusing on the sustainable use of water and land resources in developing countries. IWMI is the lead centre for the CGIAR Research Program on Water, Land and Ecosystems (WLE). The Headquarter is in Colombo, Sri Lanka with regional offices in Africa and Asia. The West Africa regional office in Accra is the one that hosts me for my internship. The vision of IWMI is to provide evidence-based solutions to sustainable management of water and land resources for the attainment of the Sustainable Development Goals (SDGs) particularly poverty and hunger reduction and the maintenance of sustainable development. IWMI is a research centre and works in collaboration with different partners, in particular, policymakers, development agencies, individual farmers and private sector organisations.

My supervisor, Dr Solomie A. Gebrezgabher is a Postdoctoral Fellow in charge of Enterprise Development and Business Model Analysis. She holds a PhD in Business Economics with a focus on analysing the overall sustainability of agricultural systems from the perspective of different stakeholder groups. Her research at IWMI currently focuses on assessing the economics of waste reuse for nutrient and energy recovery in developing countries.

During my internship, we have three main meetings. At the beginning of the internship, we met to discuss the terms of reference, the objectives and the resources available for the internship. Then we discussed during the second meeting my research proposal and the approaches and methods for a good data collection. The last meeting has been organised to discuss the data collected and their analysis. The difficulties and shortcomings have also been discussed and some recommendations for the improvement of the database have been provided. There have also been minors briefing about the progress and the difficulties encountered.

Description of the activities

My topic belongs to the Resource Recovery and Reuse (RRR) section of IWMI Ghana. Under that section, the team looks for solutions to recover water, energy and nutrients from human and agricultural waste. This helps not only to cut down the pollution level and the costs of treatment but also to increase benefits.

My activities are essentially research oriented and can be put into three categories: improvement of my research proposal and literature review, preparation (identification of potential interviewees) of interviews and data collection (secondary data), and data analysis and a short presentation.

The elaboration of the research proposal and the literature review section took a total of three months, from October to December. After the finalisation, I submitted the new version of my research proposal to my supervisors with whom I discussed its content and shortcomings. She gave me her comments and some directives for the next steps. As for the literature review section, I made extensive research on the different themes. The main focus was on faecal sludge management in developing countries (history, present development and future), resource recovery and reuse, FS-based technologies in general, process diagrams of briquettes and biogas.

I consulted several articles on the online library of IWMI. I also consulted peer-reviewed articles and reports using a thematic approach. A particular accent has been put on peer-reviewed journals.

The preparation and administration of the interviews were one of the most challenging activities. First of all, I identified the potential interviewees and I check their availability. The interviewees selected are stakeholders of the waste-to-energy value chain. The details are presented in the section "data collection".

For data analysis, see the section "data analysis" of the methodology. It is necessary to mention here that only the briquettes socio-economic analysis has been fully completed. As for the biogas, the collection of secondary data is still in progress. This is due in part on the challenges encountered during the internship.

Results, conclusions and discussion

This section presents the preliminary results of the socio-economic analysis of FS-based briquettes. The objective is to set-up a 2,500 metric tonnes of briquettes per year using both faecal sludge and municipal solid wastes as feedstocks.

Process diagram of FS-based briquettes

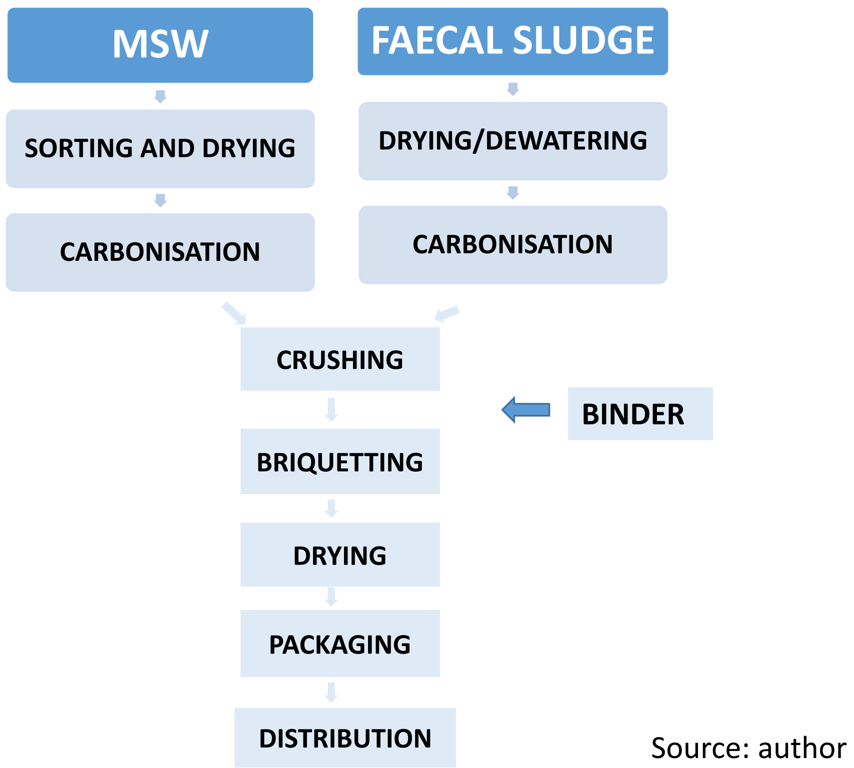

Figure n° 2: process diagram of briquettes

Figure nº 2 shows the process diagram of FS-based briquettes. Its analysis shows that there are two feedstocks for the production of briquettes: faecal sludge and organic fraction of municipal solid waste (market, abattoir, institutions like schools, prisons, hospital, etc.). The MSW is first of all sorted to remove all non-biodegradable portions like polyethylene, iron, glasses, etc. and then dried. Similarly, FS is dried in drying beds or by using flash dryer depending on the season. Then, both MSW and FS are carbonised separately in a furnace. This option is chosen to avoid the handling of untreated faecal sludge and to reduce health hazards. The carbonised FS and MSW are then crushed with a crusher/grinder and mixed. We then add a binder, preferably cassava starch or molasses in the ratio 1:10. The mixture is then pressed using a briquette machine. The final product is then dried and packaged before the distribution.

Financial analysis

Table nº 2: Financial analysis result

Financial result (US$)	
Capital cost	555,000
Revenue	415,263
Production and other costs	221,835
Profit before interest and tax	193,428
Profit before tax	184,548
Net profit	**129,183**

Source: author

Table nº 2 presents a synthesis of financial analysis. The analysis of table nº 2 shows that the capital cost of the briquette plant is US$ 555,000. The capital cost encompasses the cost of machines and equipment, the cost of land, the cost of construction and the environmental cost. The total revenue from the sale of the 2,500 metric tonnes of briquettes and the production and other costs are respectively US$ 415,263 and US$ 221,835.

The net profit after tax deduction (16%) is US$ 126,183 which is very attractive.

Environmental impacts

Under the baseline scenario, the utilisation of woodfuel leads to the emission of greenhouse gases (GHG). Similarly, faecal sludge and MSW dumping into the environment also lead to environmental degradation. On the other hand, there is an emission of GHG due to the production of FS-based briquettes. In total, six GHG (CO_2, CH_4, N_2O, CO, NO_x, and SO_2) have been considered for environmental analysis.

The emission factors and the global warming potential (IPCC, 2006 GL) of each GHG have been used to estimate the total environmental impacts of FS-based briquettes production.

Table n° 3: Environmental impacts

Environmental impacts (GHG)	
Emission savings (kg CO_2 eq.)	4,561,648
Emission from briquette business (kg CO_2 eq.)	2,126,947
Net emission savings (kg CO_2 eq.)	2,434,702
Total annual value of Carbon credit (US$/year)	**24,347**

Source: Author

Table n° 3 presents the environmental impacts of three main GHGs (CO_2, CH_4 and N_2O) whose emission depend on the level of activity and are easy to monitor. The total GHG emission saved due to the shift from the utilisation of wood and charcoal by households to the combustion of FS-based briquettes is equal to 4,561,648 kg CO_2 eq. However, the production of briquettes also leads to GHG emission that is estimated to 2,126,947 kg CO_2 eq. The net emission savings is equal to 2,434,702 kg CO_2 eq. Assuming that the carbon credit is equal to US$ 10/ton CO_2 eq., the total annual value of carbon credit is equal to US$ 24,347.

Other environmental impacts

The emission of CO, NO_x, and SO_2 depend on several factors like the machinery and the technology used. The summary of the environmental impacts attributed to the emission of CO, NO_x, and SO_2 is presented in table n° 4.

The production of briquettes results in a NO_x and CO reduction but an increase in the emission of SO_2. This might be due to the fact that the emission factors used for these GHGs are technology-sensitive. However, the net GHG emission saving is positive.

Table nº 4: Net emission of CO, NO_x, and SO_2

Environmental impacts	
Net savings in SO_2 emissions (kg SO_2)	**- 1,015**
Net savings in NO_x (kg NO_x)	1,278
Net savings in CO (kg CO)	204,720

Source: Author

Social impacts

Another constituent of the socioeconomic analysis is social impacts. It has been assessed in terms of savings for households, additional income and job creation. The social impacts results of the project are presented in table nº 4.

Table nº 4: Social impacts

Social impacts (US$/year)	
Savings from shifting to briquettes	55,573
Additional income to waste management companies	12,406
Value of employment creation	28,927
Total value of social impacts	**96,906**

Source: Author

The total expenditure saved by households for shifting to briquettes combustion is US$ 55,573. The additional income waste companies could get annually by supplying faecal sludge and MSW to the briquette manufacturing plant is estimated to US$ 12,406. The last social impact is the value of employment created but the briquette factory. This corresponds to the total salary paid to the employees and is estimated at US$ 28,927. The total social benefits of the project are equal to US$ 96,906.

Socio-economic analysis

This section presents the socioeconomic analysis (table nº 6) of the production of FS-based briquettes. It is the condensed form of the financial, environmental and social analyses previously presented.

The analysis of table nº 6 shows that the net present values of the financial and socioeconomic analyses are all positives. For the financial analysis, the NPV is equal to US$ 320,164 with an internal rate of return (IRR) equal to 27%. The benefit-cost ratio and the payback period are respectively 1.67 and 5 years. All these parameters indicate that the project is financially feasible and viable. For a project which involves environmental impacts, one cannot limit the decision making to the financial analysis. That is why social and environmental analyses are also taken into account.

Table nº 6: socioeconomic analysis

Socio-economic result	Financial value	Financial and environmental value	Social, environmental and financial value
NPV (US$/year)	320,164	447,615	1,247,358
IRR (%)	27	32	59
ROI (%)	24	28	50
BCR	1.67	1.93	3.60
PB (year)	4.20	3.54	2.01

Source: author

The NPV and the IRR of the financial and environmental analysis are respectively equal to US$ 447,615 and 32%. As for the BCR and the payback period, they are respectively 193 and 4 years. All these statistics (NPV>0, IRR>0.16, and BCR>1) shows that the project is financially and environmentally feasible and the investment costs of the project can be paid back in 4 years.

By adding the social benefits and costs, the NPV of the project is equal to US$ 1,247,358. The IRR, the BCR and the payback period are respectively 59%, 3.6 and 3 years.

We can conclude that regardless of the level of analysis performed, the production of FS-based briquettes is feasible and is socially and environmentally acceptable. The sensitivity analysis has not been performed yet due to a lack of software.

Recommendations

Two categories of recommendations worth to be made. The first category is addressed to the different stakeholders of the faecal sludge value chain and the second to the host institution.

Recommendations to different stakeholders

One of the major problems related to the production of briquettes is the quality of the MSW. Waste separation in Accra is still not yet a reality. It is necessary to sensitize the population on the benefit of waste separation. In case this will not be possible in short or medium term, waste separation can be implemented in institutions that generate a lot of organic wastes.

The production of FS-based briquettes also needs a lot of space to install the drying beds and the briquette production plant. The municipality must be ready to assist the promoters of such initiatives. The state government must also give other incentives to the promoters of environmentally friendly projects.

Recommendations to the International Water Management Institute

Many feasibility studies have been carried out on Resource Recovery and Reuse (RRR) from faecal sludge and wastewater in different regions. Now, it is high time to implement these technologies. IWMI has to find ways to support different investors willing to turn faecal sludge and municipal solid wastes into energy and soil conditioner.

IWMI must also make sure that the supervisor is not too busy to fully support the interns. They also have to give the interns the appropriate resources (necessary contacts and transportation means) to help to carry out the study. I felt a bit abandoned when I realised that I have to use my limited resources for data collection.

Self-assessment

The internship has been very rewarding in terms of personal goals achievement. I learned to work in a multicultural environment. The results-oriented principle of the Institute helps me to focus on my goals and to work consistently toward their achievement. I also learned a lot from the employees who are involved in the "Resource Recovery and Reuse" department of the Institute. They helped me to understand the state of FS management in Ghana and this helped me to redefine the objectives of my research.

As for my academic goals, they are partially met. I have been able to learn how to collect, process and analyse data using Excel sheets. The database for briquettes production is completed and that of the biogas is partially completed. Most important is the socioeconomic analysis of FS-based briquettes production performed which constitutes my greatest achievement. Theoretically, I know how to perform it but the challenge is different when it comes to use real data and to make different assumptions.

Although my personal and academic goals are to some extent met, everything did not go according to my time plan. At some times, I fell behind the schedule and this is due to several factors. It turned out that it is difficult to get information in the private sector in Ghana. They are very reluctant and I have been confronted with no response at all in certain cases and partial responses in others. Bureaucracy in public administration was another challenge I had to deal with. I had to introduce many demand letters and at the end, I got nothing. In nutshell, the data collection phase has been very challenging.

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