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# Techno-economics of Biochar and Biogas viability in Ghana

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#### Abstract

Biogas and Biochar are technological solutions that deal with sanitation and other environmental problems. The technology for producing biogas from faeces is termed bio-toilet and production of biochar from the same human waste is by means of Sol-char toilet. The study evaluated economic benefits and costs of sol-char toilet and compared with empirical benefits and costs estimates of bio-toilet. Cost Benefit Analysis was used to judge welfare change attribution of investment into Sol Char Toilet and Bio Toilet. The pyrolysis plant was fed with 4000 tons of faeces for which Sol char toilet incurred Total capital cost of US\$ 3,140,940.38, Net Present Value (NPV) of US\$9,718,817.4788, Profitability Index (PI) of 4.0942381271 and 1.4 years payback period. Bio toilet values for a total of 4000 m<sub>3</sub> (100 units of 40 m<sub>3</sub> each) were; - Total capital cost of US\$ 36,026.05, NPV of US\$89,152.75, PI of 3.4746 and 3.46 years payback period. Sol char toilet is faced with high capital requirement challenges, compared with an advantage in smaller payback period and a marginal difference in PI. The study concluded that complementary roles of sol char toilet and bio toilet in the Ghanaian economy is preferred.

Keywords: Biogas; Biochar; Cost Benefit Analysis; Profitability Index; Payback period.

### 1.0 Introduction

# 1.1 Background

The global debate on environmental management has been very profound. Improving excreta management is a major component of the Human Settlement and Infrastructure component of the Ghana Shared Growth and Development Agenda (2010 - 2013). Many Ghanaians live in communities with inadequate and poor sanitation infrastructure, leading to open defecation and periodic removal of accumulated faecal sludge produced by traditional on-site sanitation facilities like septic tanks, bucket latrines, pit latrines, Kumasi Ventilated Improved Pit (KVIP) latrines.

Challenges of traditional on-site sanitation facilities, identified by Department of the Environment UK, 1995 include water pollution, unpleasant odours, explosion and combustion, asphyxiation, vegetation damage, and greenhouse gas emissions; (Popov, 2005). These challenges impact negatively on the environment in view of the considerable amount of unpleasant odour (pollution) and health hazard accompanying them. Two recent interventions in environmental management are biogas and biochar technologies.

Generally, biogas is a combustible gas produced by the process of anaerobic decomposition and fermentation of cellulose containing biodegradable waste materials - such as cattle dung, poultry droppings, pig excreta, human excreta, crop residues (Erdogdu, 2008), and other biodegradable organic materials by the action of methanogenic bacteria.

Biogas is mainly composed of 50 to 70% methane, with the remainder being carbon dioxide, hydrogen sulphide and other trace gases (Singh and Sooch, 2004). The methane gas produced may be used for cooking, lighting, and other energy needs. The waste water is rich in nutrients so can be treated with solar treatment plant and serve as an organic fertilizer. Regarding operational biogas plants, households use the slurry as fertilizer for their crops, especially vegetables and fruits (Walekhwa et al., 2009).

On the other hand, (Lehmann, J. et al., 2009) defined biochar as carbon-rich product obtained when biomass, such as wood, manure or leaves, is heated in a closed container with little or no available air. In more technical terms, biochar is produced by so-called thermal decomposition of organic material under limited supply of oxygen (O2), and at relatively low temperatures (<700°C). This process often mirrors the production of charcoal, which is one of the most ancient industrial technologies developed by mankind – if not the oldest (Harris, 1999).

Biogas and biochar technologies use different biomass including human waste to obtain pro-poor bio-energy solids, liquids and gases. The technology for producing biogas from feces for good sanitary practices with potential to increase farm yield is termed as bio-toilet and production of biochar from the same human waste and for the same purposes is by means of Sol-char toilet. This study concentrated on Biotoilet and Sol-char toilet. In practice, two-thirds of bio toilet digesters would be filled with faeces and the remaining onethird is where gas occupies. Bio toilet, in Ghana, has received more patronage and adoption, whilst biochar is gradually receiving a boost.

The Sol-Char toilet uses concentrated solar power to transform human waste into valuable end products. The system generates valuable end products -1) Char for solid fuel, soil amendment and adsorbent -2) Disinfected urine for fertilizer -3) Excess heat for home use or water heating. Sol char can be successful in Ghana due to almost year-round availability of sun, atmospheric pollution and different user scale - family, private use, household shared, public shared municipal treatment. The benefits of sol char toilet and bio toilet include ensuring growth and development necessary to induce public investment. The financial indicators of the two technologies will also improve corporate governance in converting human faeces into useful products thereby addressing the huge disposal problem faced by metropolitan, municipal and district authorities.

Applauding technologies on the basis of their contribution to positive corporate governance is desirable, whether or not they satisfy scientific principles and benefits. Ernsting, (2011) expressed a frustrating view that the scientific benefits of biochar are not backed by the science, but the Precautionary Principle suggests that economic viability of the technologies can be assessed even in that circumstances. The Precautionary Principle requires a regulation of any activity that poses an unknown risk to human health. The Precautionary Principle is defined by the United Nations' Rio Declaration (the Earth Summit, Rio, 1992) as where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Empirical confirmation of plausible socio-economic upturn of bio-toilet has not been contradicted, for example, (Ankamah, 2016) found bio-toilet economically viable in a study involving 100 bio toilet units of 40 m<sup>3</sup> each. The objectives of this study are to - evaluate economic benefits and costs of sol-char toilet based on corresponding capacity used in a study of bio-toilet - prepare financial investments appraisal for sol char toilet, and compare that with the biotoilet investment decision criteria, namely, Net Present Value (NPV), Profitability index (PI) and Payback Period.

A firm or researchers pyrolysing feedstock into biochar may benefit directly from revenue from sale of biochar. Farmers who do Carbon sequestration benefit directly from increase in crops yield. Physicochemical properties such as pH, macronutrient content, ash content, particle size, and surface area must be investigated so as to derive agronomic benefits from biochar application for soil stability, greater than the achievement, if any, from carbon compounds infested biomass that produced the biochar, (Stefan Jirka and Thayer Tomlinson 2014). For example, Cocoa beans yield response to biochar application may largely be different from on-farm trials of a special grade fertiliser in Ghana that produced a yield rise of 62 and 107% (Food and Agriculture Organization FAO 2005).

Indirect benefit of pyrolysing biomass is in the area of waste disposal, to for example, reduced methane emissions from landfills. Indirect benefit of Carbon sequestration - Adding biochar to soil instead of using it as a fuel does, indeed, reduce the energy efficiency of pyrolysis bioenergy production; however, the emission reductions associated with biochar additions to soil appear to be greater than the fossil fuel offset in its use as fuel (Gaunt and Lehmann, 2008).

Direct cost of biochar includes the production cost of biochar. The direct production cost parameters, include feedstock collection and transportation, production technology and temperature. In (Zhang, 2010) where the feedstock was mainly agriculture or municipal waste, the transportation cost was always found to be more than the raw material collection cost.

Indirect costs of biochar are depreciation, transportation and density and dustiness of biochar which can represent fire hazard and health risks. Homagain et al (2016) found that pyrolysis process accounts for the highest share of 36 % cost in the production system; whereas land application accounts for 14 %, feedstock collection for 12 %, and transportation cost for 9 % of the total production cost. Raw material cost,

feedstock collection and transportation, pyrolysis costs including labour make up the direct production cost

## I.2 Approaches

Economic viability approaches among others includes Cost Benefit Analysis (CBA) that uses present market prices and can be applied in small and big R&D projects within a country like Ghana or a continent like Africa. There are distributional actions that overcome discounting and intergenerational equity imbalances with regards to project benefits. Strict Pareto Improvement (SPI) ensures no welfare loses arising out of projects, but if welfare loses occurs the Potential Pareto Improvements (PPI) suggests provision of compensation, which the Kaldor-Hicks efficiency accepts, even if, the compensation is not paid, (Jain, S.K., 2015).

The economic surplus method's goal is to measure the aggregated social benefits of a research project. With this method it is possible to estimate the return of investments by calculating a variation of consumer and producer surplus through a technological change originated by research. Afterwards, the economic surplus is utilized together with the research costs to calculate the Net Present Value (NPV), the Internal Rate of Return (IRR), or the Benefit-Cost-Ratio (BCR) (Maredia et al., 2000).

The econometric methods aim to estimate a marginal productivity of research during a long time period (Masters et al., 1996). Thus, the econometric models use a production function, a cost function or an analysis of total productivity of factors to estimate a change in productivity due to investment in research (Maredia et al., 2000). Anonymous (2010), assessed biogas energy from fixed dome digesters with cow dung feedstock using econometrics approach.

Crane-Droesch, A. et al (2013) employed meta-analytical, missing data, and semiparametric statistical methods to explain heterogeneity in crop yield across different soil environments globally. He reported variability response of crop yield to biochar application, ranging from cases where biochar reduced yields (negative growth) to cases when yield response to biochar increased significantly over time, by approximately 0.068 response ratio units in the second season after application, to approximately 0.117 response ratio units in the fourth season after application.

### 2.0 Methodology

Data for the study was secondary, supported by primary source of information. Commercial values for sol-char toilet were found in articles published in credible journals on the internet. The study relied on CSIR-IIR approved project proposal and signed project contracts. A discussion between a four (4) member team from University of Ghana Faculty of Agriculture and two CSIR-IIR researchers, including one M Phil student researching into biochar provided some insight into biochar.

CBA was used in this study to value biochar production and distribution, because in this study it is possible to value direct producer and consumer benefit. Ankamah, (2016) used the economic surplus approach to compute benefits of biogas. The difference between the two approaches is that where direct benefit to the producer and the consumer is not known the surplus approach can be relied upon to estimate them with market information before computations toe the line of the main CBA. To address sustainability issues regarding efficient allocation of resources and environmental management it is prudent to consider plural valuation.

2.1 Financial appraisal indicators

Yiridoe et al., (2009) and Maredia et al., (2000) included Net Present Value (NPV), the Internal Rate of Return (IRR), the Benefit-Cost-Ratio (BCR) otherwise known as Profitability index (PI) and payback period in financial indicators. In this study computation of each of the indicators utilised their respective formula. Payback period is the number of years taken to recoup the initial investment into the project. The study applied the Undiscounted Payback Period (UPBP) which is Total Cost (TC) divided by annual profit ( $\Pi$ ).

 $UPBP = TC_{/\Pi}$  (1) The basic notion of NPV is that present consumption yields more satisfaction than the same amount of consumption in the future.

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And for Profitability index (PI)

 $P1 = \Sigma$ 

(3)

(2)

Where Bi = annual flow of benefit in time period t; n = the expected life of the project; Ci = cash outlay

r = discount rate. In a single project the rule is to accept the project if the sum of NPV flows positive (NPV > 0). This implies that the rate of return by the investment is higher than the discount rate used and is greater than the opportunity cost of capital used at the discount rate. When the NPV is negative (NPV < 0) the project should be rejected.

There is a possibility of ranking inefficient decision if NPV is solely used. The NPV measure of viability is an absolute value. In addition to NPV a profitability index (PI) which provides relative measure of an investment's desirability can be used in support of viability decision. BCR is the ratio of present value (PV) of future flow of benefits to its initial cost. Accept projects with PI greater than one (1).

Investment appraisal involved technical, economic, social and financial considerations. In this study the user scale of sol char toilet targeted toilet from municipal human waste systems in urban, peri-urban and rural settings for agricultural purposes. It is envisaged that the systems contain less water just like the 100 bio toilet units of 40 m<sub>3</sub> each (total of 4000 m<sub>3</sub>) studied by (Ankamah, 2016). Therefore, this study in comparison with bio-toilet examines pyrolysis of approximately 4000 tons of faeces in Ghana, using sol-char toilet.

According to (Nic Halverson, 2014), the transmission efficiency of the current design of Sol-Char is about 90 percent and that the initial investment was US\$777,000 and an additional US\$1 million in a second round from Bill and Malinda Gates Foundation. The transmission efficiency translates to 3600 tons of biochar per year for this study.

Owners of capital will take advantage of the potential surplus in biochar to invest into biochar production enterprises. This means that famers will need to buy biochar before applying them on their farms. The biggest challenge is posed by biochar production cost and pricing as well as the fact that biochar remains unknown to farmers (Vochozka, M., et al. 2016).

It is impossible to remove, entirely, complexities and patterns relating to methods, time and computation from the scientific world of welfare economics. In this study market prices and shadow prices in constant (real) prices, (i.e. with prices fixed at a base-year) were converted to current (nominal) prices by adjusting real prices with the Consumer Price Index (CPI)] to ascertain direct and indirect benefits and costs. This is due to inflation and time value of money.

Direct revenue (producer surplus) from sale of biochar, direct benefit (increase in cocoa yield attributable to biochar application, indirect benefit with respect to carbon sequestration and direct and indirect costs were estimated. Neo-classical economics requires that benefits and costs of a project must be expressed in equivalent money value. The practice was that costs and benefits estimates were valued in United State dollars (US\$) of a particular time and this had been followed in this work.

# 3.0 Results and Discussions

Globally, the mean price for pure biochar was US\$2.65/kg. This ranged from a low of US\$0.09/kg in the Philippines and US\$0.35/kg in Ghana to a high of US\$8.85/kg in the UK, (Stefan Jirka and Thayer Tomlinson 2014). Conversion of the price in Ghana gave US\$350/ton of biochar. Direct revenue (producer surplus) from sale of biochar was estimated by multiplying output of 3600 tons by price of US\$350/ton = US\$1,260,000.

Direct benefit to the farmer consists of an increase in revenue as result of increase in cocoa yield attributable to biochar application. This study chose cocoa beans because the cocoa industry of Ghana appears to have relatively high income and well organized market, necessary to induce cocoa farmers' willingness to pay for and apply biochar. Direct benefit from cocoa yield due to biochar application is the main determinant of the economic balance, whilst soil-type is of interest to the science. Negativities concerning crop and soil health must be considered in biochar application. Ghana fixed the producer price of cocoa for the 2015/2016 season at US\$1,759 per ton and inspire Ghanaian farmers to raise the poor harvest output of 2014/2015 cropping season of 700,000 metric tons, (Theafricareport.com: 2015).

One of the observations of (Crane-Droesch, A., et al 2013) was that, the fitted model implied positive yield response over much of Sub-Saharan Africa, parts of South America, Southeast Asia, and southeastern North America. However, considering that biochar application in Ghana is at its infant stages and that cocoa farmers have low knowledge of biochar application, the suggested yield response was realistic at 0.10%. In spite of the supposed low increase in future yield; there is high optimism that farmers will embrace the growth response rate because of the cumulative soil fertility benefit of biochar amended in soil.

Farmers will embrace this growth response rate because of the cumulative soil fertility benefit of biochar amended in soil. Farmer shall not incur new annual purchase and application costs of biochar for the amended soil. Scientists have shown that the mean residence time (the estimated amount of time that biochar carbon will persist in soils) of this recalcitrant fraction ranges from decades to millennia, but for this study soil amendment benefit will persist for 20 years. Direct benefit to farmers (consumer surplus) from biochar will at least be 0.10% of 700,000 tons multiply by the new producer price of cocoa for the 2015/2016 season at US\$1,759 per ton for cocoa farmers in Ghana = US\$1,231,300.00

Indirect benefits (reduced methane emissions from open defecation, landfills, reduced industrial energy use and emissions, recovered energy from waste of pyrolysis) on one hand and the biochar pyrolysis hazards such as heat, soot inhaling and dustiness on the other hand were considered to cancel out in carbon neutral. However, carbon negative indirect benefit occurs with carbon sequestration. Johannes Lehmann, of Cornell University, estimates that pyrolysis can be cost-effective for a combination of sequestration and energy production when the cost of a CO2 ton reaches \$37, (Lehmann, Johannes 2007b).

Given that, one ton biochar can sequester 2.93 ton CO<sub>2</sub>, (Nataliya Kulyk 2012), then application of 3600 tons of biochar will sequester 10548 tons of CO<sub>2</sub>. For a market price \$37 per a ton of CO<sub>2</sub>, total value of the CO<sub>2</sub> sequestered was given by multiplying 10548 tons of CO<sub>2</sub> sequestered by the price of \$37/ton of CO<sub>2</sub> = US\$390,276.00

This study concentrated on commercial biochar ventures and so avoided domestic production valuations issues like user fee, gray water recycling system for water in the home, water savings from ditching the indoor toilet, biochar as a cooking fuel and purification of water which will increase the benefit of biochar. Since the pyrolysis unit operator typically receives a gate (tipping) fee, the waste feedstock costs are, in many instances, a source of revenue. These alternative management gate fee costs are rated at the moment at GB£50 per ton of wood waste, £22 per ton of garden and green waste, and £35 and £45 per ton of food waste and sewage sludge, respectively (Shackley et al. 2011). In Ghana the fee is GHC15 (approximately US\$4) for one human waste disposal truck of 9 m<sub>3</sub> (9 ton). Total annual gate fee is equal to 4000/9 multiply by 4 = US\$1777.78

Summation of the benefits from Production and Application of Sol char gave a total of US\$2,883,353.78.

The direct production cost parameters, include feedstock collection and transportation, production technology and temperature. The collection and transportation of human waste pose huge financial (and environmental) costs to Metropolitan, Municipal and District Assemblies (MMDAs). In (Zhang, 2010) where the feedstock was mainly agriculture or municipal waste, the transportation cost was always found to be more than the raw material collection cost.

Municipal biomass waste market is not well developed in Ghana and so the raw material cost of faeces is almost zero. On the average 9 tons of faecal sludge transported in Ghana cost GHC200.00, approximately US\$53. Total transportation cost of 4000 tons is given by 4000/9 multiply by US\$53 = US\$23,555.5555. This represents 9% of the pyrolysis cost. Total pyrolysis cost = 100/9 multiply by US\$23,555.56 = US\$261,728.44.

Indirect costs of biochar are depreciation and transportation. Cost of maintenance and replacement costs (depreciation) per annum had been shown by (Kandpal et al. 1991), and (Sinha Table 1 and Kandpal, 1990) as estimate of 4% of the capital cost of the plant. Hence cost of maintenance and replacement is estimated at 4% of US\$2,500, 000.00 = US\$100,000.00.

Inland transport costs are fairly expensive for all fertilizer products that this study considered as proxy for biochar haulage cost. According to, Chemonics International Inc. and the International Center for Soil Fertility and Agricultural Development (2007), road transport costs to the most intensive and competitive market in central Ghana (Kumasi) are US\$14 .50 per metric ton and to northern Ghana (Tamale) costs US\$38 per metric ton, principally for rice and cotton fertilizers.

Since cocoa farms are scattered at the middle zone areas of Ghana, including Kumasi and beyond but excluding Tamale. Also, due to frequent upward adjustment in petroleum prices and transport fares, transport cost of fertilizers was pegged at US\$40.00 per ton. The annual fertilizer transportation cost was valued by multiplying US\$40.00 by 3600 tons of biochar = US\$144,000.00.

Sundry expenses including human resource & finance, internet, phone, selling & distribution, taxes etc. was estimated to be 40% of total pyrolysis cost (US\$261,728.44) = US\$104,691.38 Summing the pyrolysis cost, indirect cost and sundry expenses gave total pyrolysis and distribution cost of US\$610,419.41. A 5% contingency cost was provided on pyrolysis and distribution cost against unforeseeable liabilities = US\$30,520.9705.

Hence, Total Production and Application Cost of Sol char was estimated at (US\$610,419.41 + US\$30,520.9705) US\$640,940.38 excluding capital investment cost. The study purged the initial investment (capital cost) at US\$2.5 million considering recent inflationary pressures in Ghana and the possibility of other cost of assets such as land purchase cost.

#### 3.1 Investment Appraisal

Sol char toilet; - In applying the simple profit function;  $\pi$  = TR - TC, where TR is Total Revenue/benefit and TC is Total Production and Application Cost. Therefore (profit)  $\pi$  = US\$2,883,353.78 - US\$640,940.38 = US\$2,242,413.4. Total cost is given by capital investment cost of US\$2,500,000.00 plus the production and distribution costs of US\$640,940.38 = US\$3,140,940.38. Table 1 below shows summary result of total costs and benefits from data analysis that was used to compute NPV, PI and payback period.

Summary of Costs and Benefits of sol-char toilet and bio toilet based on 4000 m3

No. of Item	Description	Sol char toilet US\$	Bio toilet US\$
1.	Total cost	3,140,940.38	36,026.05
2.	Flow of benefit per annum	2,883,353.78	28,067.00
3.	Production & distribution cost	640,940.38	17,652.42
4.	Total annual profit (Item 2 minus Item 3)	2,242,413.4	10,414.52

From Table 1 sol char caused greater economic activities as indicated by the levels of total cost, flow of benefit, production cost and profit, which will culminate into greater aggregate share in Gross Domestic Product (GDP). The seeming lucrative sol char toilet should not become a hindrance in Bio toilet research and dissemination. Also, from Table 1 NPV, PI and payback period were computed for sol char toilet and compared with results of similar indicators found by (Ankamah, 2016) for bio toilet.

Present Value Annuity Table for \$1 paid in each of the 20 periods at 22% = 4.460 - this was multiplied by the stream of equal flow of benefits (revenue) to arrive at Present value (PV) i.e. PV =  $4.460 \times US$ \$2,883,353.78 = US\$12,859,757.8588.

From equation (2), NPV is equal to discounted benefit (PV)  $-\cos t$  outlay = US\$12,859,757.8588 - US\$3,140,940.38 = US\$9718817.4788.

On the other hand from equation (3) Profitability index (PI) is discounted benefit (PV) / cost outlay = US\$12,859,757.8588 / US\$ 3,140,940.38 = 4.0942381271

From equation (1) Payback Period is Total Cost (TC) divided by annual profit ( $\pi$ ) = US\$ 3,140,940.38 / US\$2,242,413.4 = 1.4006964015 = 1.4years



Fig 1: Investment costs and NPVs of sol char toilet and bio toilet based on 4000 tons of feaces



Fig 2: Payback periods and PI of sol char toilet and bio toilet based on 4000 tons of feaces

Relying on the standard decision rules of NPV, PI and payback period both sol char toilet and bio toilet will secure high political and economic acceptance as shown in fig.1 and 2 above. Notwithstanding Sol char toilet's larger share in GDP than bio toilet, it is not to be expected that sol char toilet will produce similar larger effect on quality of life. This is because increase in aggregate pyrolysis may stimulate more greenhouse gases emission due to inability of the technology to neutralise or negate its environmental pollution.

If scientific benefits of biochar are not backed by the science as suggested by (Ernsting, 2011), but rather a subject of opinion; - the possibility is that the carbon negative assertion (diversion of C from a fast biological cycle into a slower biochar cycle) for the removal of carbon from circulation to mitigate climate change and greenhouse effect may be uncertain and so improvement in quality of life is not assured, though GDP is greater. It means that the pyrolysis process might result in carbon neutral (converting biomass into carbon and releasing biomass into the atmosphere) or even carbon positive (increase in concentration of atmospheric gases) that pollute the environment.

Biogas technology on the other hand has no geographical limitations (Taleghani and Kia, 2005) and is produced mainly from raw materials that are locally available making it a cheaper and simpler option (Gautam et al., 2009). Anaerobic digestion systems have come to symbolize access to modern energy services in rural areas and are slated to considerably improve health and sanitation, and to yield significant socioeconomic and environmental benefits (Srinivasan, 2008).

#### 4.0 Conclusion

Two technologies bio-toilet and Sol-char toilet that deal with environmental problems associated with human excreta were assessed. The study used CBA for judging the welfare change attribution of investment into Sol Char Toilet and Bio Toilet. The investment decisions were based on the values of profitability index of 4.0942381271 and 3.4746 and payback periods of 1.4 and 3.46 years for Sol char toilet and bio toilet respectively. It appears the economic viability results are in favour of sol char toilet but the results analysis was skewed positively towards support for bio toilet.

Although payback period favours sol char toilet, the technology is capital intensive. However, the positive PI is approximately 4 for both technologies. It is therefore not comprehensible, under the circumstance to allow for any form of substitution of the technologies in the economy. This avoids a challenge similar to the infamous Dutch disease (otherwise known as natural resource curse) – where it is possible to lose majority of benefits from a technology if a country concentrates on the other technology.

Therefore, this study recommends complementary roles of sol char toilet and bio toilet in the economy of Ghana. Providers of biogas should vigorously pursue construction and consultancy services and the government should facilitate popularisation and education of farmers in biochar application and benefits. Determination of choice of superior technological solution is beyond the scope of this study.

#### References

- Ankamah, E., F., (2016), An Economic Surplus Assessment of Biogas Technology in Ghanahttp://icast.kpoly.edu.gh/proceedings/in dex.php/ICAST/ICAST
- Anonymous, (2010), Socio-economic assessment of biogas production and utilization from family sized digesters in Ugandahttp://makir.mak.ac.ug/handle/10570/2 173
- Chemonics International Inc. and the International Center for Soil Fertility and Agricultural DevelopmentJune 21, (2007), Fertilizer Supply and Costs in Africa for review by The Bill and Melinda Gates Foundation
- Clarke, P., (2015), Biochar Made from Human Waste?, Introducing the SolChar toilethttps://waldenlabs.com > Food
- Costanza, R., (1997), "The value of the world's ecosystem services and natural capital" Nature 387
- Crane-Droesch, A., Abiven, S., Jeffery, S. Torm, M. S. (2013), Heterogeneous global crop yield response to biochar: a meta-regression analysis, *Environmental Research Letters*, Volume 8, Number 4
- Department of the Environment, UK, (1995), Landfill design, construction and operational practicewaste management, *Paper Number 26B, London: Crown Copyright.*
- Erdogdu, (2008), An expose of bioenergy and its potential and utilization in Turkey Energy Policy 36, 2182-2190
- Ernsting,A. (2011),Climate Change and Agriculture,Biochar - a climate smart solutionhttps://www.misereor.org/fileadmin/us er\_upload/misereor\_org/Publications/englisch/ report-2-biochar.pdf
- Food and Agriculture Organization of The United Nations Rome, (2005), Fertilizer Use By Crop In Ghana.
  - Gaunt, J. and Lehmann, J. (2008) 'Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production', *Environmental Science and Technology*, vol 42, pp4152–4158

- Gautam, R., S Baral, S. Heart. 2009. Biogas as a sustainable energy source in Nepal: Present status and future challenges, *Renewable and Sustainable Energy* Reviews 13, 248–252.
- Halverson,N.,(2014), Solar-Powered Toilet Scorches Poop Into Biocharhttps://www.seeker.com/solarpowered-toilet-scorches-poop-into-biochar-1768386273.html
- Harris, P. (1999) 'On charcoal', Interdisciplinary Science Reviews, vol 24, pp301–306 In simple terms biochar is a charcoal used as a soil amendment.
- Homagain, K., Shahi, C., Luckai, N., Leitch, M., FW Bell, F. W., (2016),Biochar Banquet & Demonstrations (2016)
- Jain, S.K., (2015) Economic Analysis of Liability Rules, Springer India 2015, DOI 10.1007/978-81-322-2029-9\_2 http://www.springer.com/978-81-322-2028-2
- Joseph, S., Graber, E.R., Chia, C., Munroe, P., Donne, S.,
- Thomas, T., Nielsen, S., Marjo, C., Rutlidge, H., Pan, GX., Li, L., Taylor, P., Rawal, A., Hook, J. (2013), Shifting Paradigms on Biochar: Micro/Nano-structures and Soluble Components are Responsible for its Plant-Growth Promoting Ability. *Carbon Management* 4:323-343
- Jirka, S., and Tomlinson, T., (2014), International Biochar Initiative 2013 State of the Biochar Industry
- Kandpal C., J. Bharati, C. S. Sinha. 1991. Economics of Family sized Biogas Plants in India. Energy Conversation Management 32, 101-113.
- Kulyk, N., (2012), Cost-Benefit Analysis of the Biochar Application in the U.S. *Cereal Crop Cultivation*
- Lehmann, J., (2007b), "A handful of carbon". Nature447 (7141)Bibcode:2007Natur.447..143L. doi:10.1038/447143a. Retrieved 11 January 2008
- Lehmann, J., and Joseph, S., (2009) Biochar for Environmental Management, *Biochar Book* Chapter 1 ES BEM 16-2 23/2/09
- Maredia, Mywish, Byerlee, Derek, Anderson Jock. (2000). Ex Post Evaluation of Economic Impacts of Agricultural Research Programs: A Tour of Good Practice.
- Masters, W., B. Coulibaly, D. Sanogo, M. Sidibé, A. Williams, (1996)The Economic Impact of Agricultural Research: A Practical Guide. Department of Agricultural Economics, Purdue University, West Lafayette, IN

- Popov V., (2005). A new land-fill system for cheaper landfill gas purification, Renew Energy 30, 1021– 9
- Shackley, J. Hammond, J. Gaunt, J. Ibarrola, R (2011), The feasibility and costs of biochar deployment in the UK
- Shackley, S., Sohi, S., (2010), An assessment of the benefits and issues associated with the application of biochar to soil, UK Biochar Research Centre, 2010 Table SPM 1
- Singh, K. J., Sooch, S. S., (2004), Comparative study of economics of different models of family size biogas plants for state of Punjab, India. *Energy Conversion & Management* 45:1329-1341.
- Sinha C. S., Kandpal C., 1990. A framework for the Financial Evaluation of Household Biogas Plants in India, Biomass 23, 39 - 53
- Sombroek, W., Ruivo, M.L., Fearnside, P.M., Glaser, B. and Lehmann J.: 2003, 'Amazonian Dark Earths as carbon stores and sinks', in J. Lehmann, D.C. Kern, B. Glaser and W.I. Woods (eds.), Amazonian Dark Earths: Origin, Properties, Management, (pp. 125–139) *Dordrecht, Kluwer Academic Publishers.*
- Srinivasan, S., (2008), Positive externalities of domestic biogas initiatives: Implications for financing,

Renewable and Sustainable Energy Reviews 12:1476-1484.

- Taleghani, G., Kia, A. S., (2005), Technical-economical analysis of the Saveh biogas power plant. *Renewable Energy*
- Theafricareport.com: (2015), Ghana fixes new cocoa price to control smuggling | West Africa
- Vochozka, M., Maroušková, A., Váchal, J., (2016), Clean Techn Environ Policy 18: 1225. doi:10.1007/s10098-016-1113-3
- World Heritage Encyclopedia (2016), World Public Library, Project Gutenberg
- Walekhwa P. N., Mugisha J., Lars D., (2009), Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications, *Energy Policy* 37, 2754-2762.
- Yiridoe, E. K., R. Gordon, B. B. Brown, 2009. Nonmarket co-benefits and economic feasibility of on-farm biogas energy production. *Energy Policy* 37, 1170-1179.

Zhang A, Cui L, Pan G, Li L, Hussain Q, Zhang X, Zheng J and Crowley D., (2010), Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain,