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ORIGINAL PAPER

Economic Viability Assessment of Small-Scale Biomass Composting Project Within a Developing Country Context

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Abstract

Promoting investment in biomass composting is necessary to halt finite resource depletion and transition consumption and production processes into sustainable circular bioeconomy paths. This notwithstanding, there is a lack of demonstrable evidence of the economic viability of such investment, which often disincentivises the adoption of composting and other greener production technologies by entrepreneur. To address this problem, this study evaluates the economic viability of composting as technology for valorising biowaste and tropical aquatic invasive plants in the Owabi catchment in the Ashanti Region of Ghana. Using data from interviews with key informants, pilot study findings and market survey, a cost–benefit analysis (CBA) was performed to determine the economic viability of composting organic waste under public and private ownership models (M1P1 and M1P2, respectively) as well as aquatic invasive plants under similar models (M2P1 and M2P2). The findings show that a positive net present value (NPV) of GHS 507,520.31(US $64,243.08) to GHS 1,217,358.77 (US $154,095.92) is achievable from the alternative scenarios modelled. Each of the scenarios analysed (M1P1, M1P2, M2P1 and M2P2) resulted in a benefit–cost ratio (BCR) greater than 1 and an internal rate of return (IRR) greater than 28%. These results remain robust even with sensitivity analysis based on pessimistic assumptions about costs, benefits, discount rate and project lifespan. The study thus concludes that investing in a small-scale compost production technology with biowaste and aquatic invasive plants as feedstock is a feasible business with positive social, economic and environmental net benefits. Future development in the carbon credit market will make biomass composting even more economically viable to investors and thereby contribute to sustainability and the transition to a circular economy.

Keywords Biowaste · Invasive plants · Composting · Profitability · Ghana

Highlights

- There are many environmental, social and economic benefits of composting.
- Composting biomass is a strategy of choice for circular bioeconomy transition.
- Economic appraisal of composting is needed to attract investors.
- Cost-benefit analysis of different composting scenarios reveals promising outcomes.
- CBA justifies investment in compost production as a profitable circular economy business.

Extended author information available on the last page of the article

Introduction

Waste management approaches have evolved from merely municipal and public service activity to a business industry with a global market value of over 1 trillion US dollars in 2020 [1]. The value chain in waste management is lengthy from waste collection to recycling, reuse and remanufacturing to disposal with millions of jobs created in the process [2]. As global appeal and attention toward sustainable waste management practises and circular economy increase, the emergence of livelihood options within the waste management value chain is expected to increase [3]. A World Bank report has predicted that in the next few decades, waste is likely to be seen globally as a resource rather than an environmental nuisance [4]. There is growing evidence of drastic movement from waste disposal to recovery and valorisation, especially in many developed countries such as Sweden, France and Switzerland among many others [5]. It is expected that such trends will trickle down to developing countries as infrastructure development and technology advance in these countries.

In developing countries, the largest proportion of waste generated, collected and disposed of is organic waste (biowaste) [4]. These classes of waste which include agricultural waste, garden and park waste and part of municipal solid waste have high resource potential. Biowaste can be converted into high calorific value briquettes, nutrient-rich compost, biofuel and diesel among many other valuable products [6]. With the high demand for these products, biowaste valorisation could serve as an important source of income and livelihood option for many in developing countries. Compost production for instance is one of the most promising businesses and pathways of biowaste utilisation that have enormous environmental and economic benefits [7]. The International Centre for Trade and Sustainable Development (ICTSD) has reported that composting as a business can generate net profit margins exceeding 10% with the average annual revenue ranging from $500,000 to over $1 million for small and medium-sized compost businesses [8].

In many developing countries in the tropics where organic wastes are most abundant, composting as a business has much more promising potential economically and for the benefit of the environment. Many studies have demonstrated that composting is the strategy of choice for biowaste valorisation and waste management, especially in low-income and developing countries context [9–12]. It has been suggested that the adoption of composting technology is more likely to be driven by economic motives rather than the desire to get rid of waste [13]. This means that demonstrable evidence of economic viability and profitability is expected to incentivise the adoption of composting technologies. Studies have shown that composting organic waste can be profitable but there is no consensus on that. A study by Sabki et al. [14] shows that large-scale composting plant operations are often faced with economic inefficiencies and profitability challenges. A study by Pandyaswargo and Premakumara [15] in Indonesia, however, shows that small-scale government-affiliated compost plant operations are profitable with a payback period of 6 years.

A study by Galgani et al. [16] found that composting business in the context of a voluntary carbon market is not economically viable without receiving external subsidies. A similar operation in Taiwan based on the study by Chen [17] was found not to be profitable with 110 years payback period. However, a study by Opoku [18] in Ghana showed a strong economic case for investing in composting given a cost–benefit ratio of at least GHS2 in economic benefit per GHS1 invested with little sensitivity to even "pessimistic" data assumptions. There are important contextual variables such as scale of production, location and access to feedstock that have an important bearing on the economic viability and profitability of compost production. According to Galgani [16], the economic viability of composting is dependent on local conditions such as land cost, distances to be covered by waste and fertiliser transportation, market price and compost demand as well as the efficiency of the composting process. Evidence from the existing literature suggest that globally, there is inconclusive evidence on the profitability and economic viability of biomass composting as a business. It is, however, essential that given the potential of biomass composting in promoting sustainable and efficient resources use, empirical evaluation of the economic viability from both global and local case studies is conducted.

The Owabi catchment in Atwima Nwabiagya North District in the Ashanti Region of Ghana is an enclave where the potential for biomass composting is most promising but least undertaken. Ineffective collection and management of biowaste have led to pollution of water bodies including the Owabi dam, leading to eutrophication and excessive growth of aquatic invasive plants in the dam [19]. There is evidence of technical proof for composting these biomass classes, yet industrial-scale commercial application especially by businesses and entrepreneur remain scarce. An earlier study by Banunle et al. [20], for instance, proved that both the solid biowaste (organic waste) generated in this area as well as the aquatic invasive plants are good feedstock that produced compost of high quality for agricultural use. What is lacking in the current body of literature is demonstrable evidence of the economic benefits in biomass composting to serve as incentives for entrepreneurs and businesses to invest in it.

This study offers a shift in paradigm beyond technical proof of concept for biomass composting to establishing demonstrable evidence of economic viability of composting as an investment to facilitate uptake and transfer to industrial-scale commercial application by businesses and entrepreneur. By appraising and analysing the profitability and economic viability of composting under different scenarios and models with biowaste and/or aquatic invasive plants feedstock, this study has established investment pathways for small-scale composting business. The study has also contributed to improving the methodology and academic evidence on profitability and economic viability of biomass composting as bioresource valorisation pathway. Also, by establishing the economic viability of biomass composting, this study contributes to policies and programmes needed to incentivise biomass composting businesses with prospects in hastening the transition to a global sustainable circular bioeconomy.

The above contribution of this study is made by answering the following questions:

i. What are the costs and benefits associated with small-scale biomass composting in a developing country context?
ii. How economically viable is composting of biomass (biowaste and aquatic invasive plants) as a business?
iii. How sensitive are the estimates of profitability to cost, benefits, discount rates and lifespan of composting business with biowaste and aquatic invasive plants as feedstock?

Materials and Methods

Study Design and Approach

The methodological approach to this study involves the use of cost–benefit analysis (CBA) to find out the viability of composting as a means of valorising household solid biowaste and aquatic invasive plants within the Owabi catchment. Cost–benefit analysis (CBA) is a business, investment or project appraisal tool that seeks to compare the benefits of project(s) with their costs for rational decision-making [21]. A Pareto efficiency rule is often applied to CBA in which case the decision to invest in the business or project is taken if the positive outcomes (benefits) make at least one person or community better off without making others worse off. The technical feasibility of composting biowaste and invasive plants has already been piloted, and the outcome shows both invasive plants and biowaste-produced compost of high quality that has a similar effect to NPK fertiliser in grain yield improvement. This study is therefore a follow-up to establish whether, in addition to technical feasibility, the project is economically viable.

The approach to this study is to find out through CBA whether there is an economic justification for the adoption of the small-scale composting technology for invasive plants and biowaste valorisation in the Owabi catchment. The CBA provides useful information to stakeholders as well as investors regarding the economic viability of setting up composting facilities for the management of household biowaste and aquatic invasive plants in the Owabi catchment. Cost–benefit analysis (CBA) often serves two purposes, namely determining whether an investment or project is sound in terms of its benefits outweighing cost and providing the basis for comparing alternative investment based on their total expected cost and benefits [22]. In this study, CBA is employed for the purpose of determining the economic viability of alternative models and scenarios of compost production based on the feedstock used and ownership. The steps in this approach involve a description of the project and scenarios, identification and measurement of impacts, monetisation of the impacts as cost and benefits and estimation of financial/economic ratios.

Project Area Description

The proposed area of the biomass composting project modelled is the Owabi catchment in the Ashanti Region of Ghana. The Owabi catchment is a 13-km^2 area located at latitudes 6°47′3.32″–6°41′52.31″ N and longitudes 1°44′0.81″–1°37′53.04″ W covering a reservoir, forest reserve and a Wildlife Sanctuary Ramsar Site [23]. There are eleven (11) villages/communities within the immediate neighbourhood of the catchment and many more within the statutory catchment area. Agricultural activities, especially vegetables and cereal production, is the major livelihood within the catchment [24]. The high number of farming households in the area guarantees demand for compost from this project. On the other hand, there is high organic waste generation which will serve as feedstock for the composting plant. The Owabi dam within the catchment also has large quantities of aquatic invasive plants that can also serve as the composting feedstock. A study by Banunle et al. [20] proved that the organic waste (biowaste) and invasive plants in the Owabi catchment are suitable feedstock for high-quality compost production that improves agricultural productivity. A map of the Owabi catchment as the project area is presented in Fig. 1.

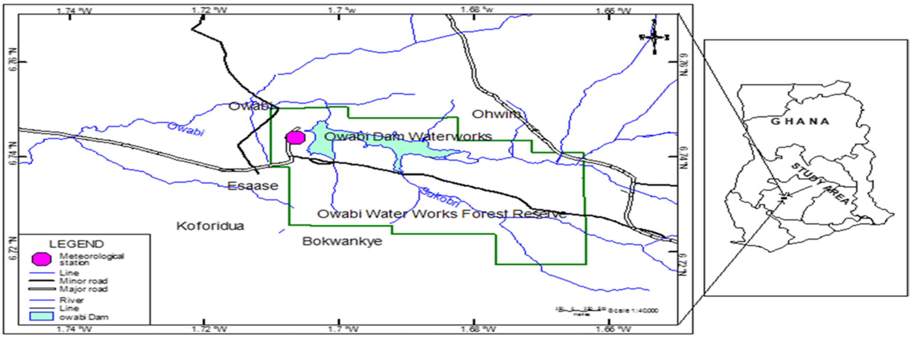


Fig. 1 Map of proposed project area (Owabi catchment). Source: Osei et al. [25]

Description Projects and Scenarios

Composting technologies vary in scale and methods. The common composting methods include in-vessel composting, the aerated static pile composting method and the windrow composting methods [26]. This study considered only the in-vessel composting method which involves confining compost materials into a vessel, container or building [27]. Small-scale in-vessel technology normally takes a maximum of 5 tonnes of waste daily, medium scale 5 to 100 tonnes daily and large scale takes more than 100 tonnes daily [15]. The small-scale type in-vessel composting technology is proposed and evaluated in this study due to its low capital requirement, easy to start and operation with minimum know-how, good-quality compost and low operational costs [15]. Two models are considered, one with household solid biowaste as the feedstock (M1) and the other with aquatic invasive plants as the feedstock (M2). Two scenarios are also evaluated, one where the project is state/public funded (P1) and owned and the other which is privately funded and owned (P2).

Impacts Identification and Measurement

An important consideration in the CBA is the accurate identification and estimation of the category of impact as either cost or benefits [28]. It is widely recognised that the process of composting and the use of the finished compost have impacts on the environment, economy and society. Thus, a full cost accounting approach to composting from a sustainability perspective must consider the "triple-bottom-line," which involves accounting for social, economic and environmental cost and benefits [29]. According to Sinden [30], many CBAs often fail to account for the environmental and social costs and benefits due to the problem of quantification. In addition, for private-owned project scenarios, the focus is often on costs and benefits that are internal to the project and not environmental and social costs and benefits [31]. For this study, the public-ownership scenario considers full cost and benefits accounting that covers environmental and social costs and benefits as well while the private-ownership scenario considers only economic cost and benefits.

Economic Cost and Benefits

Economic costs and benefits are often easier to identify and measure as they are the direct costs and benefits associated with the production of the output of interest [32]. The economic cost variables for compost production include fixed cost items such as building, land, equipment/plant and vehicle together with operational cost items such as labour, input cost and fuel among others [29]. These items are dependent on the scale of production and context of the project. For this project which involves a small-scale in-vessel composting plant, the fixed cost includes the cost of land, equipment and machinery, a building that includes office space, a fence around the plant and a carting vehicle for transport. The variable cost includes labour costs (wages), fuels, administration costs, cost of compost testing and laboratory analysis, depreciation of machinery/ vehicles, taxes, licence and insurance of assets and feedstock collection costs. The economic benefits from the project include revenue from sales of compost and tipping fees from waste generation units.

Environmental Cost and Benefits

Although difficult to measure quantitatively, composting has numerous environmental impacts in the form of negative and positive externalities [33]. Composting may contribute positively or negatively to greenhouse gas emissions (CO_2 and CH_4), acidification, eutrophication, ecosystem toxicity and pollutants [34]. The environmental cost of composting is defined as the sum of the monetized value of pollutants and environmental degradation caused by composting and environmental benefits as the monetized value of avoiding or reducing these pollutants [35]. The direct quantifiably observable indicators of the environmental cost and benefits can be estimated using the human health cost and benefits associated with increasing or decreasing pollution of land, water and air. For this reason, the study estimated environmental costs/benefits as the cost incurred or saved from sanitary-related illnesses within the catchment.

The estimated environmental cost and benefits used in the study are monetary values derived from either the estimated or real financial cost of environmental pollution to human well-being. Specifically, cost savings from sanitation-related illnesses were used to measure environmental costs and benefits based on the human capital approach. Using this approach, the cost saved included savings from labour productivity loss from getting infested with sanitary-related illness in the project area and direct treatment costs. The labour productivity loss cost was estimated using a formula by [18] as follows:

$$\boldsymbol{PL} = \sum\{(\boldsymbol{SD_i} \times \boldsymbol{WR_i} \times \boldsymbol{ID_{fc}}) \tag{1}$$

where PL is the labour productivity loss, SD is the average number of sick days related to sanitary-related illness, WR is the wage rate and ID is the disease incidence given by the population of people within the project area affected by sanitary-related illness annually. A survey conducted in the project area reveals that residents suffer from four (4) sanitation-related illnesses including infectious diarrhoea, cholera, dysentery and malaria. The survey reveals that 38% of the inhabitants suffer at least one sanitation-related illness with an average of 4 sick days and a treatment cost of GHS120.0. An assumed cost saving of 10% from these illnesses and a wage rate of the current minimum wage of 13.53 GHS/day were used in the estimation. The overall net environmental benefits include the labour productivity loss cost saved and the average treatment cost.

Social Cost and Benefits

Besides the economic and environmental costs and benefits, there are societal/social costs and benefits that are associated with composting organic waste. The social cost associated with compost generally includes odour that may be suffered by individuals living closer to the plant [36]. This social cost is, however, considered quantitatively negligible and not included in the analysis. The social benefits also include education opportunities within the catchment for students and farmers, employment creation and a reduction in disamenity associated with current practises of indiscriminate littering of waste [35]. Other social benefits include cost savings from avoiding landfilling. The most quantitatively relevant social benefits that is convertible to monetary value for this project is employment creation. The monetary benefits of employment creation are estimated as the income tax paid by individuals employed in the project and cost savings from avoided landfilling. The income tax at 10% of the gross salary of the employee and the cost savings from avoiding landfilling per unit waste were estimated as the social benefits of the project.

Data Collection

The data for the project includes data from both primary and secondary sources. A pilot study carried out in the study area from 2019 to 2021 involving the collection of biowaste and harvesting of invasive plants is relied on for an estimate of the cost of harvesting invasive plants and tipping fees in the project area. Interviews with key informants at the Kumasi Compost and Recycling Plant (KCARP) helped in obtaining estimates of the market price of compost. Other opinion leaders including the Agricultural Extension Agent (AEA), Officers-in-charge of waste management at the Atwima Nwabiagya North District Assembly as well as Chiefs in the Owabi catchment were interviewed to obtain data on labour cost, land and landfilling costs in the study area. A public health officer at the Atwima Nwabiagya North District Health Directorate was interviewed for data on the prevalence of sanitary-related illness and the cost of treatment for such incidences. The cost and benefit items, description and source of data are presented in Table 1.

Financial/Economic Analysis

The economic viability of the proposed project scenarios was evaluated using a combination of benefit–cost ratio (BCR), net present value (NPV) and internal rate of return (IRR). These analyses are followed up with sensitivity analysis to determine the robustness of the analysis. The benefit–cost ratio (BCR) was estimated as the ratio of the sum of the present value of the gross benefit of the project or investment to its gross cost all expressed in monetary terms. Mathematically, BCR is given by Eq. 2 as follows:

$$BCR = \frac{\sum_t^n B_t/(1+r)^t}{\sum_t^n C_t/(1+r)^t} \tag{2}$$

where 'B' is the benefit, 'C' is the cost, n is the lifespan of the project, 't' is time and 'r' is the discount rate. The decision rule is that a BCR ≥ 1 is needed to consider a project worthwhile to invest in as this indicates the project recovers its cost. The net present value (NPV) is given as the sum of the present value of the cash flow stream which is calculated

Table 1 Cost and benefits categories and estimation

Items	Description	Source of data
Investment/fixed cost		
Machinery and equipment	Cost of plant equipment and machinery	Quotations from supplier
Auxiliary facilities	Weighing bridge; construction/installation; fencing	KCARP
Transport truck	Truck, tricycles (2) and official vehicle	Retailers in Kumasi (Ghana)
Land	Half acre of land at Owabi	Interview with landowners
O&M		
Fuel; utilities and maintenance	Cost of fuelling trucks, water and electricity and annual maintenance	KCARP
Labour	Wages and salary for plant manager, assistant plant manager; driver (2) and account and administrative officer	Interview
Feedstock collection and enrichment	Harvesting of invasive plants and enrichment with poultry manure	KCARP
Disposables	PPEs, waste collection bags and buckets	KCARP
Revenue		
Compost sales	Fifty kg of compost at GHS30	KCARP
Tipping fee	Fees paid by waste-generating units	Interview
Net environmental benefits	Treatment cost of sanitary-related illness and labour productivity loss	ANNDA
Net social benefits	Income tax of employees at 10% and avoided landfill cost	ANNDA

NB. *KCARP* Kumasi compost and recycling plant, *ANNDA* Atwima Nwabiagya North District Assembly by taking the difference between the present value of the benefits and the present value of the costs. Mathematically, NPV is represented by Eq. 3 as follows:

$$\mathbf{NPV} = \frac{\mathbf{R_t}}{(1 + \mathbf{r})^{\mathbf{t}}} \tag{3}$$

where R_t is the returns or net cash flows at time '*t*', *r* is the discount rate and *t* is the time of cash flows. The decision rule for NPV is to accept all projects with positive NPV when discounted at the opportunity cost of capital. In addition to the NPV, the internal rate of return (IRR) is estimated as the discount rate at which the net NPV of the project is equal to zero (NPV = 0). The IRR is important because it shows the average earning power of the money invested in the project over the project's lifespan. Mathematically, the IRR can also be estimated given the Eq. 4 below.

$$\mathbf{IRR} = \sum_{\mathbf{t-1}}^{\mathbf{t}} \frac{\mathbf{C_t}}{(1 + \mathbf{r})^{\mathbf{t}}} - \mathbf{C_0} \tag{4}$$

where Ct is the net inflows at time '*t*', *r* is the discount rate, *t* is the time and C_0 is the total initial investment. The decision rule using IRR is to accept projects with IRR equal to or above the opportunity cost of capital. The opportunity cost of capital in this analysis is taken to be the treasury bill rate.

Discount Rate and Sensitivity Analysis

Due to the time value of money, it is important when conducting CBA to convert costs and benefits to their present value using an appropriate discount rate [37]. The selection of discount rate is subjective but has an important influence on the outcome of the analysis and decision taken. Generally, the higher the discount rate, the lower the PV of costs and benefits, and the lower the discount rate, the higher the PV of the costs and benefits [37]. Most CBA analyses rely on a discount rate between 2 and 18%. Similar studies in the USA by Sutton [29] and Kocher [38] used discount rates of 3 and 2%, while studies by Aborah [39] and Opoku [18] in Ghana used 5 and 9%, respectively. It is important that the discount rate reflect the present cost of capital given by the Bank of Ghana as 18.4%. It is worth noting that the COVID-19 pandemic and the Russia-Ukraine conflict contributed to this, and therefore it is expected that interest rates will fall sometime in the future. For these reasons, a discount rate of 12% is used in the analysis.

Sensitivity analysis is also conducted to determine how net benefits vary if the anticipated values of the parameters change in the course of the project. The need for sensitivity analysis is to improve the robustness of the results of estimates of benefit and cost under the risks and uncertainties associated with the project [40]. The one-at-a-time (OAT) approach to sensitivity analysis, which involves varying one-factor-at-a-time (OAT) to determine their unique impact on net benefits, was used [41]. The sensitivity analysis identifies the effect of each variable on the project benefits and ranks them based on the variables with the most impact on net benefits to the variable with the least impact on net benefits.

Results and Discussions

Introduction

This section presents the results from the analysis of the cost and benefits of the project. The analyses are underpinned by the following assumptions for project cost and benefits.

- The project is assumed to run for 20 years starting from 2023 to 2043.
- The plant process 730 tonnes per year with every tonne of waste processed resulting in 250 kg of compost.
- Depreciation of machinery is assumed to be 10% and that of buildings is 4%.
- The discount rate for both cost and benefits is taken to be 12%.
- A 2% increase in O&M cost is expected annually from the second year of the project.
- Benefits are assumed to increase annually by 1% from 2nd year of the project to the end of life.

Cost Analysis

Biomass composting as a business investment requires investment costs as well as operational costs that run through the lifespan of the project [42]. Apart from the cost of machinery, the construction of auxiliary facilities such as weighing bridges, building and purchasing of vehicles for transportation is needed. The estimated investment (capital) cost as well as the operations and maintenance (O &M) costs of the modelled biomass composting options studied are presented in Table 2. It is noted from the results that the total machinery and equipment cost is GHS 232,513.65 for the proposed plants with a capacity of processing 2 tonnes of waste per day. The machinery and equipment cost represents 54.1% of the total investment cost under the publicly owned scenario (M1P1 and M2P1) and 52.6% of the privately owned and operated scenarios (M1P2 and M2P2). Auxiliary cost and facilities for the public-owned scenario are estimated to be GHS 70,400, representing 16.4% of

Table 2 Baseline cost of models and scenarios of compost plant

Fixed	M1P1	M1P2	M2P1	M2P2
Machinery and equipment (GHS)	232,513.65	232,513.7	232,513.7	232,513.7
Auxiliary facilities (GHS)	70,400	82,400	70,400	82,400
Other fixed assets (Vehicles) (GHS)	127,000	127,000	127,000	127,000
Sub-Total (GHS)	***429,913.65***	***441,913.7***	***429,913.7***	***441,913.7***
O&M				
Fuel, Utilities and Maintenance (GHS)	55,200	55,200	55,200	55,200
Wages and Salary (GHS)	100,200	100,200	100,200	100,200
Disposables (GHS)	2650	2650	2650	2650
Enrichment with Poultry manure (GHS)	2500	2500	2500	2500
Harvesting of Aquatic invasive plants	-	-	-	24,000
Sub-Total (GHS)	***160,550***	***160,550***	***160,550***	***183,550***
Total (GHS)	**590,463.65**	**602,463.65**	**590,463.65**	**625,463.65**

N.B: USD1.00 = 7.95USD

their total investment cost while that of privately owned is GHS 82,400 representing 18.6% of their total investment cost. High investment costs (machinery and equipment) have been observed as a hindrance to the growth of composting businesses in many developing countries [36]. Small-scale models such as that of this study have a higher chance of adoption as many small- and medium-sized businesses may be able to afford such investment.

The other important aspect of the cost analysis is the operations and maintenance cost which runs through the entire lifespan of the project. In this study, the total operational cost for the Model 1(M1P1 and M1P2) and the public-owned version of Model 2 (M2P1) alternative is GHS 160,550.00 annually while that of the privately owned Model 2 (M2P2) is GHS 183,550 annually. For each of the alternatives, the largest proportion of O&M costs comes from labour (wages and salary). For Model 1, labour (wages and salary) account for 62.4% of the total operational cost while fuel, utilities and maintenance account for 34.4%. The cost of wages and salary also represented 62.4% and 54.6% of O&M costs for M2P1 and M2P2 alternatives as well. For the M2P2, an additional cost of GHS 24,000 annually is expected to be incurred on the harvesting of aquatic invasive plants from the Owabi dam, while the cost of enrichment of the compost with poultry manure is estimated to be GHS 2500.00 per year for all models and scenarios. The annual operations and maintenance cost are about 37.3% to 42% of the investment cost of each composting model plant.

Generally, composting plant operational cost is known to be high [43]. A study by Chen (2016) in Taiwan found the compost production cost to range from NT$ 2897 to 23,117 per tonne of waste, the equivalence of US$ 89.807 to US$ 716.627 in 2016. In this study, even with small-scale plant that processes 2 tonnes per day, the operational cost ranges from GHS 298.84 (US$ 37.83) to GHS 366.01 (US$ 46.33) per tonne. A major driving force of O&M cost of composting projects is wages and labour cost. A similar study in Ghana by Opoku [18] found labour (wages and salary) cost to be more than twice that of fuel, utility and maintenance. This observation is consistent with the findings of this study as labour costs in the investment options were estimated to be about 54.6 to 62.4% of the operational and management (O&M) costs. This means that improving labour use efficiency is critical to reducing the cost of biomass composting business and enhancing the profitability and economic viability of such investments.

Benefits Analysis

The results on the benefits of the project given the different models and scenarios are presented in Table 3. Generally, the benefits from the biomass composting business depend on the stream of benefits, unit price and quantity obtained. The economic benefit from biomass composting is mainly derived from the sale of compost although some economic benefits can be obtained from tipping fees and carbon credits among others [44]. With the unavailable carbon credit market in the study area, the economic benefits were derived mainly from sales of compost and tipping fees with the results presented in Table 3. The market price of compost in the proposed project is GHS 30.00 per 50-kg bag, and an estimated 250 kg of compost is expected from the processing of 1 tonne of biomass. There are varied observations regarding the compost turnover with Yeo et al. [45] reporting about 25% turnover based on 14.2 metric tonnes of mature compost produced from 59.4 metric tonnes of organic waste processed. A study by Zulkeplia et al. [46] also obtained 14.6 tonnes of mature compost from processing 73 tonnes of organic waste, given a turnover of less than 10%. A study by Banunle et al. [20] reported about 25% turnover for biowaste and invasive plant feedstock; as such, the turnover of 25% was used.

Table 3 Estimates of benefits at the baseline

Economic	Unit	Qty	M1P1	M1P2	M2P1	M2P2
Sales of compost (GHS)	30	10,950	328,500	328,500	328,500	328,500
Tipping fee/tonne (GHS)	6	2190	13,140	13,140	-	-
Social benefit (GHS)			***341,640***	***341,640***	**328,500**	**328,500**
Treatment cost saved	120	133	15,960	-	-	-
Labour productivity loss	54.12	133	7197.96	-	-	-
Environmental benefits (GHS)			***23,157.96***	**-**	**-**	**-**
Income tax (employee)	10,020	1	10,020	-	-	-
Landfill cost avoided	8	4380	35,040	-	-	-
Social benefits (GHS)			***45,060***	**-**	**-**	**-**
Total (GHS)			**380,658**	**341,640**	**328,500**	**328,500**

USD 1 = GHS 7.95

Based on the turnover of 25% and GHS 30.00 per 50 kg of compost, the result shows GHS 328,500 of revenue is expected for each investment model from sales of compost. The average tipping fee per tonne of organic waste in the study area was discovered to be GHS 6.00, resulting in GHS 13,140.00 additional revenue for M1P1 and M2P2. M2P1 and M2P2 with aquatic invasive plants as feedstock do not benefit from tipping fees as this feedstock does not constitute municipal waste disposed of in the study area. The overall economic benefits for M1P1 and M2P1 are GHS 341,640.00 each while that of M2P1 and M2P2 is GHS 328,500.00 each. The investment options with organic waste (biowaste) as feedstock have higher economic benefits than those with aquatic invasive plants because the latter do not benefit from the additional revenue from the tipping fee to be paid by waste-generating units.

One of the limitations in the estimation of benefits from compost investment is the difficulty in expressing, in monetary terms, the social and environmental benefits [33]. The use of proxy measures such as willingness to pay for preventing environmental degradation as well as cost and labour productivity loss saving from sanitation-related illness avoidance have emerged as some credible estimates of environmental benefits. Using these proxies, the net environmental benefit resulting from sanitary-related illness treatment cost saved is projected to be GHS 15,960, while the cost saved from labour productivity loss is estimated to be GHS 7197.96 per year. These benefits, however, apply to only M1P1, as M2P1 and M2P2 do not contribute to a reduction in sanitary-related illness since the feedstock (aquatic invasive plants) does not cause sanitary-related illness. The M1P2 option also looks at investment from private entities with a focus on personal profits and not public good as a benefit. It is worth noting that the environmental benefits are at best pessimistic estimates as several other benefit items which are unquantifiable such as prevention of disamenity and reduction in greenhouse gas emission among others are not included. The results, however, indicate a frontier of progression in the quantification of the environmental benefits of composting.

The social benefit of composting is also largely a convoluted concept [47]. This is not because these benefits are unknown but because their estimation and quantification are shrouded with difficulties and uncertainties [29]. A much more straightforward approach used in this study is the monetary benefits of employment creation and landfilling costs avoided with composting. From this approach, the social benefits in the form of income tax from employees amount to GHS 10,020.00 while avoided landfill cost is GHS 35,040. The overall net social benefit obtained for M1P1 is GHS 45,060 per year. These results of net social benefit exclude some other quantitatively negligible benefits such as serving as education opportunities, prevention of disamenity, public health and improvement in quality of life. Many past studies fail to account for the social benefits of composting [30]. Thus, the findings of this study give benchmark estimates for appreciating the social benefits of composting in monetary terms.

Cost–Benefit Analysis

The high level of investment required in the biomass composting business necessitates the conduct of a cost–benefit analysis (CBA) to appraise such projects. At the most basic level, CBA allows for the comparison of alternative investment projects in order to rationally determine the most economically viable option [48]. The commonest approach to CBA is the determination of net present value (NPV), benefit–cost ratio (BCR) and internal rate of return (IRR) [49]. Positive NPV, BCR > 1 and IRR greater than the prevailing interest on secure bond (usually Treasury bill) are indicators of economic viability from CBA. In this study, the CBA was performed by estimating the NPV, BCR and IRR of the four (4) investment options for biomass composting given the estimated cost and benefits as well as the projected lifespan and discount rate. The results from the analysis are presented in Fig. 2 to Fig. 4. It is noted from results on the NPV that all four alternative models are positive, indicating that the returns from each model at the end of the project lifespan are higher than the expenses. This observation is an indication that on average, the inflows from the options examined exceeded the outflows through out the project lifespan.

Specifically, the results presented in Fig. 2 show that the highest NPV GHS 1,217,357.77 was recorded for M1P1, that is the public/state-owned composting plant using biowaste as feedstock. On the other hand, the least NPV of GHS 507,520.31 was observed in M2P2. In order of NPV, M1P1 > M1P2 > M2P1 > M2P2. These results of economic viability are further confirmed by the BCR and IRR. Each option has BCR > 1, indicating that each investment project results in extra benefits over the costs. The results in Fig. 3 show the lowest BCR to be 1.23 (M2P2) and the highest is 1.67 (M1P1). This means that for the M1P1, for every GHS 1.00 investment returns GHS 0.67 more while for the M2P2 alternative, every GHS 1.00 investment yielded extra returns of GHS0.23.

The IRR for alternative investment models presented in Fig. 4 ranges from 28 to 50.7%. IRR represent the earning power of capital in each investment project, and therefore IRR

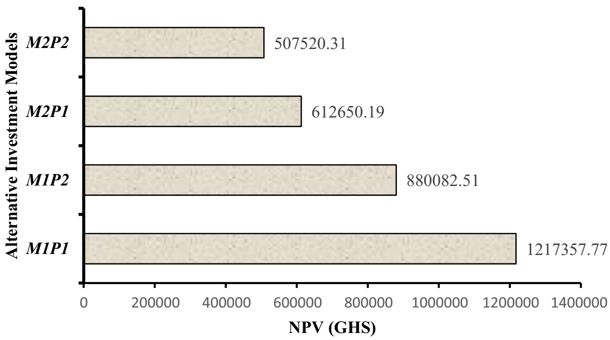


Fig. 2 Net present value (NPV) of different biomass composting models

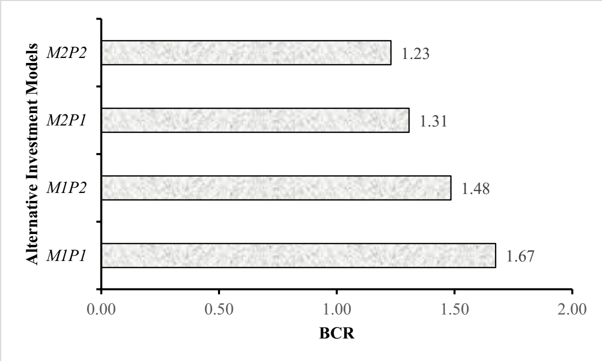
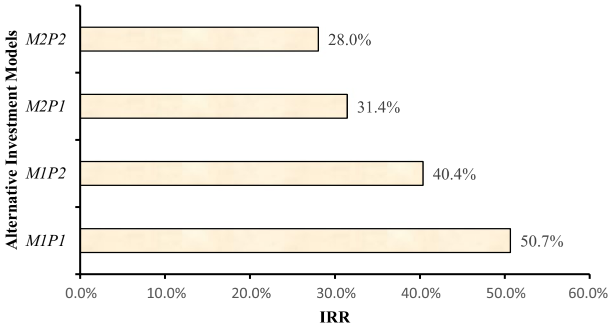


Fig. 3 Benefit cost ratio (BCR) of different biomass composting models

Fig. 4 Internal rate of return (IRR) for different biomass composting models



of 50.7% means that the M1P1 alternative earns back all investment and operational cost on the project and pays 53% for money utilised. Likewise, the M2P2 option with an IRR of 28% means that investment in this project will recover all costs and pay 28% for capital/ money used. Based on the IRR, only investments that offer more than 28% interest payment would be considered worthwhile than the M2P2, and investments that pay interest of more than 50.7% will be considered more worthwhile than M1P1. With the current T-bill rate of 19%, and not expected to increase over 25% any time soon, it can be concluded that all alternative models are economically worthwhile.

Similar observation has been made in past studies regarding the profitability of composting. For instance, a study by Hsu [44] found composting different agricultural biomass to be economically viable with greater than 1 BCR and positive NPV. Askarany and Franklin-Smith [50] also found that generally composting is an economically viable means of transforming biomass into clean products for agricultural use. The economic viability of small-scale options such as this has been linked to the less labour-intensive nature of such investments [26]. This is confirmed in this study given that labour cost alone constituted over 50% of O&M costs of each investment. Within a similar study area contest, Opoku (2015) also found composting organic waste to be profitable with a BCR greater than 1 and a positive NPV. Large-scale composting plants, however, have been less cost-effective and not profitable, according to a study by Pandyaswargo and Premakumara [15] in developing

Asia. Thus, selecting the optimal plant capacity and scale of production is important for cost-effectiveness and the economic viability of biomass composting investment.

Sensitivity Analysis

Although the estimated CBA parameters are based on current information and expert projections, there are underlying assumptions and uncertainties that may change the conclusions drawn in the future. For this reason, sensitivity analyses were performed to examine the influence of variation in estimates on the robustness of the conclusion drawn with the NPV, BCR and IRR. As Razavi et al. [40] acknowledged, sensitivity analysis enhances the robustness of CBA outcomes and allows for better communication and understanding in order to reduce the risk of uncertainties that may cause fluctuation in CBA outcomes. The cost of compost production can be driven up by inflation and other macroeconomic indicators [51]. The benefits being driven by sales of compost and tipping fees can also change dramatically due to demand and supply factors as well as government policies such as subsidies or taxes [52]. Against this backdrop, the sensitivity analysis involves the determination of changes in NPV, BCR and IRR as a result of a 5%, 10% and 15% increase in production cost and a decrease in benefits.

The results of the CBA outcomes sensitivity to increase in cost and decrease in benefits are presented in Table 4. As the results show, a 5% increase in operational cost leads to a 7.4%, 10.3%, 16% and 21.7% decrease in the NPV for M1P1, M1P2, M2P1 and M2P2, respectively. This shows that the investment most sensitive to cost increase were M2P2 and M2P1. There is an even more sensitivity to a reduction in benefits as a 5% reduction in benefits leads to 12.4%, 15.3%, 21.3% and 26.7%, respectively for M1P1, M1P2, M2P1 and M2P2. This means that the NPV of each investment will decrease more with a decrease in benefits than cost at the same proportion. The NPV for each investment option

Table 4 Sensitivity to production cost and benefits

		(%) Increase in cost			(%) Decrease in benefits		
	Baseline	5%	10%	15%	5%	10%	15%
M1P1							
NPV	1,217,357.76	1,127,109.55	1,036,861.33	946,613.10	1,066,241.66	915,125.55	764,009.44
BCR	1.67	1.59	1.52	1.46	1.59	1.51	1.42
IRR	50.66%	46%	42%	39%	46%	42%	37%
M1P2							
NPV	880,082.51	789,306.96	698,531.41	607,755.85	745,302.84	610,523.16	475,743.48
BCR	1.48	1.41	1.35	1.29	1.41	1.34	1.26
IRR	40.38%	36.57%	33.08%	29.85%	36.38%	32.34%	28.22%
M2P1							
NPV	612,650.19	512,852.24	413,054.30	313,256.35	482,219.73	351,789.28	221,358.83
BCR	1.31	1.24	1.19	1.14	1.24	1.18	1.11
IRR	31.44%	27.67%	24.21%	21.00%	27.48%	23.48%	19.38%
M2P2							
NPV	507,520.31	397,248.65	286,976.99	176,705.34	371,872.64	236,224.96	100,577.29
BCR	1.23	1.17	1.12	1.07	1.17	1.11	1.05
IRR	28.03%	24%	21%	17%	24%	20%	15.42%

remains positive even for a 15% increase in cost and a 15% decrease in benefits, indicating that the conclusion drawn with NPV is robust.

The result also shows similar percentage decrease in BCR of 4.8%, 4.7%, 5.3% and 4.9% is observed for a 5% increase in cost and a 5% decrease in benefits, respectively for M1P1, M1P2, M2P1 and M2P2. However, at higher (10% and 15%) increase in cost and decrease in benefits, the BCR varies across the different investment options. The results show that BCR decreased by 9.0%, 8.8%,9.2% and 8.9% for a 10% increase in cost but by 9.6%, 9.5%, 9.9% and 9.8% for a 10% decrease in benefits for M1P2, M2P1 and M2P2, respectively. This also means that a 10% or more decrease in benefits affects the BCR more than the same percentage increase in cost. Among the alternative projects compared, the lowest BCR of 1.05 is obtained when benefits for M2P2 decrease by 15% with all other options having higher BCR for all the increases in cost and decrease in benefits of 5 to 15%. This observation is also proof of the robustness of the BCR estimate for each of the investment options. Except for M1P1, a 5% decrease in benefits results in a higher proportion decrease in IRR than that of a 5% increase in cost. This further shows much more sensitivity of IRR to a decrease in the project benefits as compared to a similar percentage increase in operational cost. Overall, IRR below 20% is recorded for M2P1 at a 15% decrease in benefit and on M2P2 at a 15% increase in cost, and a 15% decrease in benefits.

The results generally show that while NPV, BCR and IRR are all affected by an increase in production cost and a decrease in benefits, the conclusions remain largely robust even at a 15% increase in cost and a 15% decrease in benefits. With BCR however, a decrease in benefits in M2P1 by 15% and a 15% increase in cost or decrease in benefits for M2P2 lead to IRR below the current treasury bill of 19%. A similar observation made by Sutton [29] for up to a 7% increase in cost proves the CBA estimate of composting production investment to be robust. With up to a 15% cost increase and a 15% benefits decrease, all the projects retained positive NPV and BCR > 1. On this basis, it can be inferred that the conclusion that small-scale biomass composting investment is economically viable is valid even if the cost were to increase by 15% or expected benefits decline by 15%.

Besides costs and benefits, CBA estimates are also sensitive to the project lifespan and discount rate. The lifespan of a compost project can be shortened by technical failures, natural disasters and other unexpected factors, which intend to reduce the duration of inflows and lower the NPV, BCR and IRR [53]. Likewise, changes in discount rates influence the present value of future returns and hence affect CBA results [37]. To address this, sensitivity was conducted to compare CBA for the lifespan of 10 and 30 years compared to the assumed 20 years lifespan and a discount rate of 6 and 18% compared to the 12% used. The result as presented in Table 5 shows that a discount rate of 6% could result in as high as a 51.04% increase in NPV for M2P2 and 42.3% increase in NPV for M1P1. On the other hand, an increase in the discount rate to 18% resulted in a reduction in NPV of M1P1 from 1,217,357.76 to 746,825.31 (38.6% reduction) and the NPV for M2P2 decreased from GHS 507,520.31 to GHS 231,777.28 (representing a 54.3% reduction).

These results mean that the CBA estimate with regards to NPV increases tremendously if the discount rate decreases from 12 to 6% and also decreases highly with an increase in discount rate up to 18%. The BCR equally increases with a decrease in the discount rate to 6% and decreases if the discount rate were to increase to 18%. These observations imply that stable macroeconomic conditions especially those related to the interest rate are needed for the estimated CBA to be robust over the project lifespan. This observation is due to the fact that future returns are undervalued when the discount rate is high and highly valued when the discount rate is low [54].

Table 5 Sensitivity of CBA to discount rate and project lifespan changes

		Discount rate		Project lifespan	
	Baseline	6%	18%	10 years	30 years
M1P1					
NPV	1,217,357.76	2,108,907.158	746,825.3072	809,222.4	1,420,434
BCR	1.67	1.81	1.54	156.97%	1.73
IRR	50.66%			49.76%	50.68%
M1P2					
NPV	880,082.51	1,564,184.813	1,564,184.813	570,122.1	985,446.5
BCR	1.48	1.60	1.36	1.40	1.51
IRR	40.38%			38.92%	40.63%
M2P1					
NPV	612,650.19	1,199,966.486	231,777.28	334,137	865,856.4
BCR	1.31	1.42	1.20	1.210136	1.375518
IRR	31.44%			28.84%	31.79%
M2P2					
NPV	507,520.31	1,036,257.40	231,777.28	258,311.5	745,549.8
BCR	1.23	1.32	1.14	1.15	1.29
IRR	28.03%			24.99%	28.57%

The effect of variation in the project lifespan is also noted in the results presented in Table 5. A decrease in the expected lifespan cuts short the returns from the project while on the other increase in the lifespan increases the number of years returns are received. These phenomena account for the decrease in the NPV, BCR and IRR when the expected lifespan of the project is reduced to 10 years but the increase in the NPV, BCR and IRR when the project lifespan increases to 30 years. What is notable from the results is that if each of the projects were to last only 10 years, the NPV for M1P1 would be GHS 809,222.4 while that of M2P2 would be GHS 258,311.5. It is worth noting that the positive NPV, BCR > 1 and IRR, not less than 24.99% will be obtained from each of the project options if the project lifespan is reduced to 10 years. These observations also demonstrate the robustness of the investment options to the lifespan of the projects. Many past studies especially that of Lin et al. [55] and Gebrezgabher [56] demonstrate that many biomass composting investments pay back in less than 10 years. In this case, with even shorter periods of operation, such investment project remains profitable as noted in this study.

Conclusions and Recommendations

Turning the tide toward sustainable circular bioeconomy approaches requires investment in technologies for efficient valorisation of bioresources. Composting has been widely acclaimed as one of the most suitable circular economy pathways for sustainable management of organic waste especially in developing countries. However, encouraging investment in composting requires demonstrable evidence of not only technical feasibility but also economic viability. Building on earlier research on the technical feasibility of compost production using biowaste and aquatic invasive plants, this study established the economic viability as well based on a full-accounting cost–benefit analysis. The analysis reveals that positive NPV and BCR greater than unity are achievable from small-scale biomass composting investment with biowaste and aquatic invasive plants under four alternatives of public and private ownership scenarios. Even with pessimistic assumptions about costs, benefits, discount rate and project lifespan, all four alternatives remain economically following sensitivity analysis. These observations lead to the conclusion that investing in the production of compost from biowaste and aquatic invasive plants as a business is feasible with positive social, economic and environmental net benefits. It is important to recognise that although the CBA estimate is based on best estimates of current costs and benefits, users of the findings need to take caution that dramatic changes in macroeconomic indicators such as interest rates (discount rate) and inflation may affect the conclusion to a larger extent in the future.

Notwithstanding this, with the wide availability of biowaste and aquatic invasive plants in the study area and many other parts of Ghana and other countries within the tropics, an opportunity is offered for investment in composting as a sustainable circular economy business. The fact that these feedstocks are renewable guarantees the self-sustainability of composting business and the opportunity to contribute to addressing the burgeoning global trend of resource depletion and environmental degradation. Given the potential of biomass composting as a pathway for transition into a greener and more sustainable future, government and international development bodies should provide support and subsidies to incentivise such investment. We recommend the need for the recently established Ghana Carbon Market Office (CMO) to hasten the development of emission trading schemes (ETS) to enable individuals and firms to harness the environmental benefits of composting. Future development in the carbon credit market will make biomass composting investment even more economically viable to investors in both the private and public sectors and thereby contribute to sustainability and transition to a circular economy.

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Author Contribution All authors contributed to the study's conception and design. Data collection and analysis was undertaken by AB under the supervision of BF-B, KM and NE-M. RA provided guidelines for the economic analysis. The first draft of the manuscript was written by AB, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics Approval and Consent to Participate Verbal informed consent was obtained from participants before the interview.

Consent for Publication The participants consented to the submission of the research report for publication.

Competing interests The authors declare no competing interests.

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