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Techno-Economic Models for Optimised Utilisation of *Jatropha curcas* Linnaeus under an Out-Grower Farming Scheme in Ghana

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Abstract: Techno-economic models for optimised utilisation of jatropha oil under an out-grower farming scheme were developed based on different considerations for oil and by-product utilisation. Model 1: Out-grower scheme where oil is exported and press cake utilised for compost. Model 2: Out-grower scheme with six scenarios considered for the utilisation of oil and by-products. Linear programming models were developed based on outcomes of the models to optimise the use of the oil through profit maximisation. The findings revealed that Model 1 was financially viable from the processors' perspective but not for the farmer at seed price of $0.07/kg. All scenarios considered under Model 2 were financially viable from the processors perspective but not for the farmer at seed price of $0.07/kg; however, at seed price of $0.085/kg, financial viability was achieved for both parties. Optimising the utilisation of the oil resulted in an annual maximum profit of $123,300.

Keywords: jatropha; out grower farming scheme; techno-economic models; profit optimization

1. Introduction

Diminishing fossil fuel sources coupled with concerns about climate change presents the need to focus on renewable energy sources to address the escalating energy demands of growing economies like Ghana. Ghana in recent times has therefore developed policies in an effort to ensure the development of renewable energy and its integration into the national energy mix. Key among such policies is the Ghana's Renewable Energy Act (Act 832), which was established in 2011 and has since rejuvenated interest in the development and investment in the renewable energy sector. Within the energy sector, biofuel production is considered to play a significant role due to the potential for sustainable development in rural areas. The establishment of Ghana's draft bioenergy policy was there developed to aim at substitution of national petroleum fuels consumption with biofuel by 10% by 2020 and 20% by 2030 [1]. Though, these targets may not be achieved because of the short time span [2] efforts at cultivating promising biofuel crops to achieve the set targets in the long term must be considered a national priority. Among various biofuel crops, Jatropha is identified to have the greatest potential to contribute towards meeting the targets [1].

Jatropha is a shrub crop which can reach a height of 5 m, but can grow up to 10 m under favourable conditions [3]. It is easily established and grows very quickly with a gestation period of only a year. The plant can be cultivated in large-scale plantation or grown as hedges in homestead and around farms. The shrub starts bearing fruit from the first year of planting but economic yield start from the third year [4]. Jatropha has a lifespan of 40–50 years and, according to [5], annual seed yield ranges from 0.4 to 12 t/ha. The major energy carriers from jatropha are the raw oil and its esters. Recent studies have reported the utilisation of the oil for biodiesel production, direct use in modified diesel engines and for soap production [6–8]. The by-products such as the press cake and fruit hulls can also be diversified into a range of bioenergy sources through gasification, briquetting, anaerobic digestion, pyrolysis and combustion.

It is often argued that, for jatropha to fulfil the promise of contributing to sustainable rural development, its cultivation must be small in scale, inclusive and community-based [9,10]. Jatropha cultivation in Africa has in some areas been deployed as large-scale stand-alone plantation as well as out-grower model schemes and a mixture of both in some situations. The most prevalent farming model is, however, large-scale plantation [11]. Currently, jatropha production and processing schemes emerging in Africa include; large scale plantation, contracting small holders as out-growers [12] and independent small-scale farmers (some organised in associations or cooperatives) who are locally producing, processing and utilising the oil in their communities [13]. Plantation scheme has been reported to be more effective, however, concerns have been raised on the use of large stretch of land and its consequential effects on food security and the environment. Case studies into the failure of jatropha cultivation businesses using the large scale plantation model has been reported in Sub-Saharan African countries including Ghana [14–16] However, cultivation of jatropha as a hedge plant in poor rural areas without alternative income generation opportunity has been reported to be the most profitable [14,17]. This is corroborated by [18], who also reported that, the only profitable business case for jatropha is where farmers are planting the crop as hedges.

Out-grower scheme based on strong farmer based organisations (FBOs) in countries with weak agricultural infrastructure can be the best model to uplift poor rural communities. This model has been demonstrated for high value cash crop such as cocoa in Ghana. However, these cannot be extrapolated into the same context with jatropha. Unlike cocoa, jatropha is a low value crop which presents the need for a more diversified utilisation of its oil and by-products in other to make it economically attractive for processors and farmers. Out-grower farming scheme is more preferable over large-scale plantations since large size of land is not required and farmers cultivate the seeds on their own lands. However, despite the expected benefits an out-grower scheme offers ahead of plantation scheme, economic studies have indicated otherwise. A study by [19] on economic viability of an out-grower model indicated that, the estimated financial profitability was bad for seed growers even at relatively good seed market price of $0.14/kg, but it was marginal for the processors. In a later study, [17] asserted that jatropha production and processing projects that link seed production with local processing and utilisation of the oil is likely to achieve financial viability. It was furthermore reported that finding higher value use of the by-products after processing is likely to increase the prospects of financial viability for both processors and farmers.

Recent reported failures of large scale jatropha plantation in Ghana [16] provides the need for critical consideration of the out-grower model which has been reported to contribute to sustainable development in rural areas. However, given the economic uncertainties and risk of failure, rural poor farmers and processors are not expected to likely take up production without technical and economic assessments that points to sound economic benefit for both the processor and farmer. The balance for achieving economic viability for the processors and farmers that ensure sustainable seed production and corresponding processing and utilisation of the oil and its by-products requires researchers' urgent attention. This study therefore seeks to develop techno-economic models for optimised utilisation of jatropha oil and its by-products under an out-grower farming scheme. Specifically, the financial viability of jatropha production and processing for two business models under the out-grower farming scheme using Net Present Value (NPV) and Internal Rate of Return (IRR) was determined. Linear programming model was also developed to optimise the use of the crude jatropha oil for profit maximization.

2. Materials and Methods

The methodology for this study consisted of three main sections, interview with key informants and literature information on costs and technical parameters in jatropha, briquette, biogas, compost, soap and electricity production (see Appendix A). The data were fed into the two business models considered to determine its economic viability. Linear programming models were later developed to optimise the use of jatropha oil based on data from the models. Detailed description of the methods, materials and models are presented in the sections below.

2.1. Models Description

Two business models were developed based on different utilisation of jatropha crude oil and its by-products under an out-grower farming scheme. Total out-grower farmers farm sizes totalling 200 ha was considered as base scenario for the technical and cost benefit analysis of the two models. This was premised on the average plantation size that was established in Ghana in the past. Profitability before tax was considered in the Cost-Benefit Analysis (CBA) of the models.

2.1.1. Description of Model 1

In this model, small holder farmers or farmer groups (out-growers) are contracted by a central company to produce jatropha seeds by means of intercropping or as hedges. This model uses the buy-back agreement at fixed price method where a processing company signs an agreement with farmers in which the farmer agrees to sell all his/her produce to the processing company. The company agrees to buy all the seed at a fixed price per kilogram. After the fruits are harvested, collected and de-hulled, the seeds are pressed. The extracted oil is exported. In this model, seedlings, extension services and capacity building are provided to farmers. The pressed cake is used to produce compost and sold to farmers at a subsidised price as a fertiliser supplement. The model outlay is shown in Figure 1.

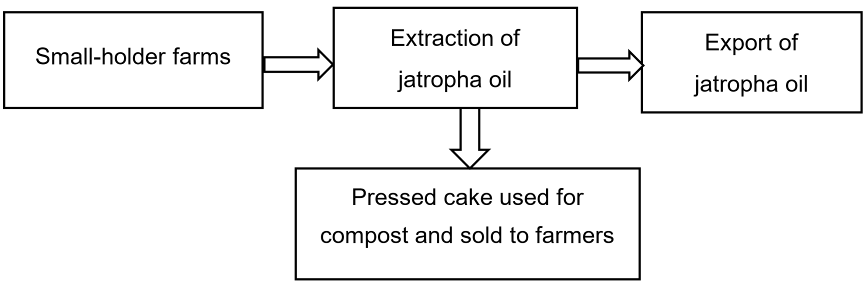

Figure 1. Schematic description of Model 1.

2.1.2. Description of Model 2

This model builds on Model 1 with 100% local utilisation of the oil (Model 1 had an export component) and utilisation of by-products for soap, biogas and briquette production (see Figure 2). Six main scenarios (see Table 1) were considered under this model.

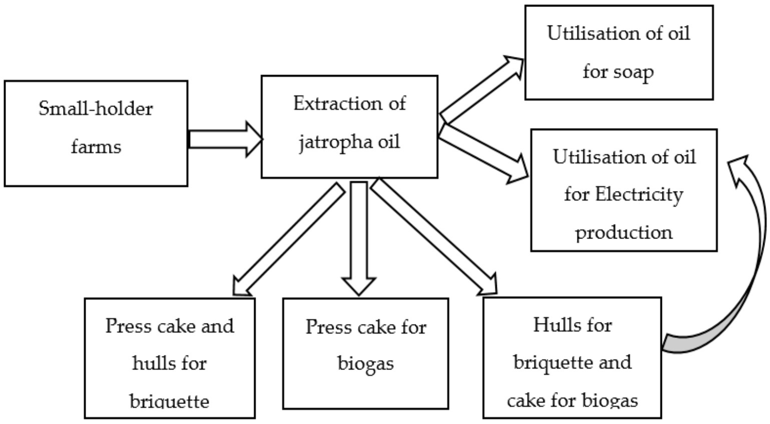

Figure 2. Schematic description of Model 2.

Table 1. Descriptions of scenarios under Model 2.

Scenario	Description
Scenario 1 (S1)	Utilisation of oil for electricity generation, residual oil for soap and press cake for biogas production.
Scenario 2 (S2)	Utilisation of oil and biogas for electricity generation and residual oil for soap production.
Scenario 3 (S3)	Utilisation of oil for electricity, press cake for biogas, fruit hulls for briquette and residual oil for soap production.
Scenario 4 (S4)	Utilisation of oil for electricity generation, residual oil for soap production, press cake and fruit hulls for briquette production.
Scenario 5 (S5)	Utilisation of filtered and residual oil for soap production, press cake for biogas and fruit hulls for briquette production.
Scenario 6 (S6)	Utilisation of filtered and residual oil for soap production, press cake and hulls for briquette production.

2.2. Financial Appraisal Methodology

2.2.1. Financial Return on Investment

The method used for the determination of the financial return was the Discounted Cash Flow (DCF) approach. The purpose of the financial analysis was to use the projects cash flow forecasts to calculate suitable net return indicators. Emphasis was placed on two financial indicators: Net Present Value (NPV) and Internal Rate of Return (IRR). The NPV was determined using Equation (1):

$$NPV = \sum_{t=0}^{n} a_{tS_t} = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \ldots + \frac{S_n}{(1+i)^n} \quad (1)$$

where S_t is the balance of cashflow at time "t"; a_t is the financial discount factor; $a_t = \frac{1}{(1+i)^t}$, where t is the time between 0 and n (the time horizon) and i is the discount rate.

The IRR was calculated using Equation (2):

$$NPV\,(S) = \sum \frac{S_t}{(1+IRR)^t} = 0 \quad (2)$$

where symbols have same meaning as in Equation (1).

Cash flows were discounted over a period of 25 years for jatropha plantation, 25 years for the electricity generation, biogas production and oil extraction, 20 years for briquette, compost and soap production at a rate of 18% which is Ghana's inflation rate as at 26 June 2015 [20]. A rate of

5% of equipment and machinery cost was assumed to be operation and maintenance cost in the financial analysis.

2.2.2. Estimation of Costs and Revenue

Method used in the estimation of the various cost components (investment, working capital and operation and maintenance cost) of the projects consisted of interview with key stakeholders and data from literature (see Appendix A). The respondents consisted of various stakeholders in jatropha, biogas, briquettes, compost and soap production businesses. The investment cost included cost of building, machinery and civil works, cost incurred for jatropha plantation, and other expenses. The operating costs comprise all the data on the disbursements foreseen for the purchase of goods and services, which are not of an investment nature since they are consumed within each accounting period. The data were organised into three main categories:

(1) The direct production costs (consumption of materials and services, personnel, maintenance, general production costs).
(2) Administrative and general expenditures.
(3) Sales and distribution expenditures.

The total revenue to be accrued includes revenues from: crude jatropha oil, electricity, soap, biogas, briquettes, and compost. The unit price of all items was determined using the relation shown in Appendix A.

2.2.3. Criteria for Assessing the Projects Viability

As indicated earlier the economic indicators used to assess the projects viability was the NPV and IRR. If the NPV of a prospective project is positive, the project is accepted. However, if NPV is negative, the project is considered not financially viable and rejected. In ranking projects, the one with higher NPV is preferred. The higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR was used to rank the two business models. A business model that depicted IRR lower than the interest on savings at 25% [21], was considered not financially viable.

2.2.4. Sensitivity Analysis

Sensitivity analysis was carried out by varying one element at a time and determining the effect of that change on IRR and NPV. The key parameters considered included:

(1) Variation in seed yield: 0.55, 4 and 7.5 tonnes/ha.
(2) Variation in jatropha oil prices: 473, 600 and 1000 USD per tonne.
(3) Variation in the purchase price of jatropha seeds: 0.05, 0.07 and 0.16 USD per kg.
(4) Thirty per cent increase and decrease in the selling price of briquette, biogas, soap, compost and electricity.
(5) Changes in the discount rate: discount rates from 0% to 30% were considered.

2.3. Methodology for Optimising Jatropha Oil and By-Products Utilisation

Every business establishment seeks to maximise profit with the available resources. This section of the study therefore sought to optimise utilisation of jatropha oil through profit maximisation. A linear programming model was therefore developed with set objective functions and constrains. The set objective function, which is a mathematical function that consists of a decision variable denoted with (Z), was used to represent maximised profit or minimised cost. On the other hand, the constrains denoted with (C) which may be represented with an equation or no equation using decision variables was used to express the limitations of the model or decision in order to research the model objectives as reported by [22]. The linear programming models were solved using Excel 2016 optimisation tool. Table 2 presents the objective functions and constraints.

Table 2. Objective function and constraints for optimising the utilisation of jatropha oil.

Objective Function	Constraints
$Z_1 = Maximize\ (P) = F_1X_1 + F_2X_2 + F_3X_3$	$C_1 : X_1 + aX_2 + bX_3 \leq g$ $C_2 : X_1 \leq 0.6g$ $C_3 : X_2 \leq c$ $C_4 : X_3 \leq 0.7d$ $C_5 : X_1, X_2, X_3 \geq 0$

where X_1 = Quantity of oil required for export (L); X_2 = Quantity of electricity required (kWh); X_3 = Quantity of soap required (kg); F_1 = Unit profit of oil export (USD/L); F_2 = Unit profit of Electricity generation (USD/kWh); F_3 = Unit profit of soap production (USD/kg); P = Maximum profit (USD); a = Quantity of oil required to produce 1 kWh of electricity (L/kWh); b = Quantity of oil required to produce 1 kg of soap (L/kg); c = Quantity of electricity produced from total available oil (kWh); d = Quantity of soap produced from total available oil (kg); g = Total quantity of oil available annually (L); and 0.6, 1 and 0.7 are fractions of oil, electricity and soap to be sold annually.

3. Results and Discussion

3.1. Technical and Cost Benefit Analysis of Model 1

This model was built on purchase of seeds from contracted small holder farmers or farmer groups (out-growers) that produce jatropha seeds by means of intercropping in their farms or as hedges. This model also considered the export of jatropha oil and utilisation of press cake for compost. Table 3 presents technical parameters and assumptions considered for the establishment of the out-grower scheme. Based on a required farm size of 200 ha for the base scenario, 400 farmers are required with the assumption that each farmer cultivated or intercropped 0.5 ha of his/her total land holding with jatropha. Planting spacing of 3 m by 2 m for intercropping translates into a total of 833 plants for each farmer. A planting distance of 1.5 m for hedges implies that total planting distance of 556 m is required for each farmer to achieve the required plant population. Purchase price of seeds at $0.07/kg was considered for the base scenario. With annual fruit yield of 4.5 tonnes/ha/year, annual quantities of fruit hulls, crude oil, press cake and residual oil expected to be generated are 306, 183, 387 and 22 tonnes, respectively.

Table 3. Technical parameters and assumptions for out-grower schemes.

Parameter	Value
Cropping model	Intercropping/hedges
Planting spacing for intercropping (m)	3 by 2
Area covered per plant (m^2)	6
Plant population per hectare	1667
Total plant population	333,333
Size of farm for each farmer (ha)	0.5
Number of plants per farmer	833
Total number of farmers required	400
Planting distance for hedges (m)	1.5
Total planting distance required by each farmer to achieve the required plant population (m)	555.6
Purchase price of jatropha seeds (kg) (USD)	0.07

Farmers that work with jatropha seed cake in the raw form expose themselves to potential risks due to the widely known toxic elements of jatropha that are potentially present in the pressed cake [23]. Composting has been shown to reduce the toxicity and oil content of the press cake [24]. The production and sale of compost from press cake was therefore considered in this model. Table 4 presents assumptions and technical parameters for the compost production. Using a Windrow system and mixing at a ratio of 2:1 of press cake to bulking agents (grass clippings), 290,021 kg of compost are expected to be generated from 387 tonnes of press cake annually. A unit price at $0.17/kg was considered for revenue generation from the compost.

The cost benefit analysis for this model was considered from two perspectives: processor and small holder farmer. Investment and annual operational cost for the processor were $78,706 and $122,288 respectively (see Figure 3). Revenue expected to be generated from this model is presented in Figure 4. At a discount rate of 18%, NPV and IRR values for the processor were $119,504 and 39.16%, respectively. CBA analysis from the farmers' perspective generated NPV and IRR of $−88.65 and 7.05%, respectively. This indicates that the purchase price of seeds of $0.07/kg produced financial viability for processors but non-viability for the farmer, even with inclusion of revenue from carbon credit (see Table 5).

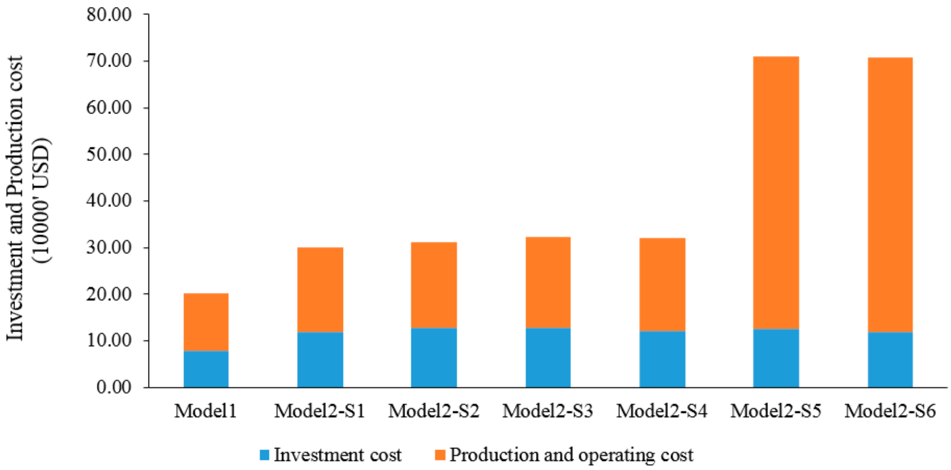

Figure 3. Investment and production cost for models and scenarios.

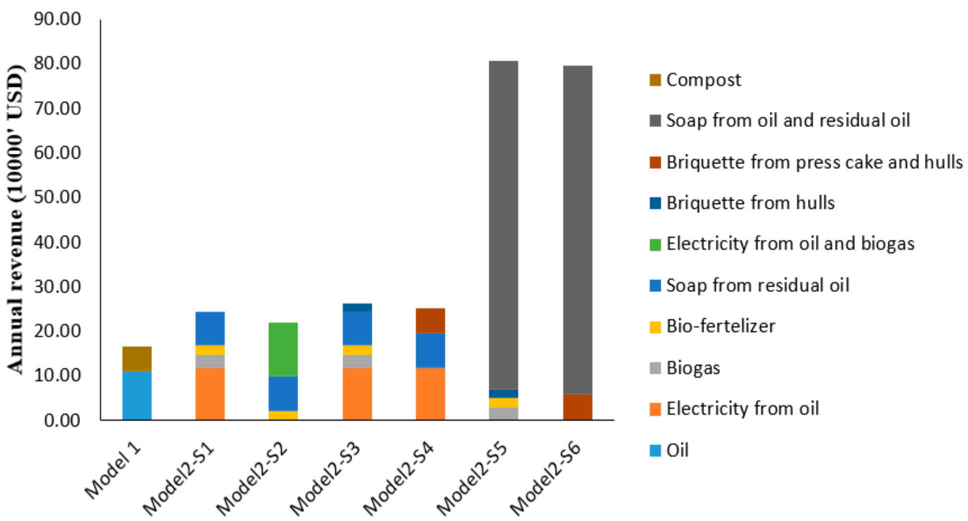

Figure 4. Annual revenues generated from the models and scenarios.

Critical variables identified for sensitivity analysis of this model were discount rate, purchase price of seeds, seed yield and prices of crude oil and compost. Figures 5 and 6 present variation of NPV as discount rate varies from 0% to 30% for the processor and farmer, respectively. It indicates that the business venture for the processor is financially viable for the range of discount rates considered. However, financial viability can be achieved if the discount rate is ≤7%. Sensitivity analysis on the selling/purchase price of seeds revealed that, at seed price of $0.05/kg, Model 1 is financially viable for a processor or an investor who buys the seeds from the out-growers but not profitable or viable for the farmers engaged as out-growers. The situation is vice versa when the purchase price of seeds is increased to $0.16/kg (See Table 6). Moreover, financial viability is achieved at seed purchase price of $0.1/kg for both an investor or processor and an out-grower farmer engaged. This translates into NPV and IRR of $37,185 and 25.32%, respectively, for the processor while NPV and IRR of $119 and 29.65%, respectively, were realised for the farmer. Even though the Model 1 is not viable for the farmer in the base scenario, increase in seed yield to 7.5 tonnes/ha/year produced positive NPV and IRR. Details of the rest of the sensitivity results for this model are shown in Table 6.

Table 4. Technical parameters and assumptions for compost production.

Parameter	Value
Composting method	Windrow system
Quantity of press cake available for composting (tonnes)	387
Volume of press cake available (m^3)	1734
Mixing ratio of press cake to bulking agents (grass clippings)	2:1
Volume of bulking agent required (m^3)	867
Total volume of input material (m^3)	2601
Quantity of compost generated annually (50% volume of input materials) (m^3)	1301
Quantity of compost generated (kg)	290,021
Capacity of sieves (t/h)	1
Power of motor of sieves (kW)	3
Operational hours	290
Electricity consumption (kWh)	870
Unit price of sieves (USD)	1000
Unit price of compost thermometer (USD)	10
Unit price of moisture meter (USD)	90
Unit price of PH meter (USD)	25
Number of days for compost to reach maturity	40
Required temperature (°C)	48–65
Moisture content (% by weight)	50–60
C:N ratio	25–35:1
PH	6.5–8
Oxygen concentration (%)	10
Size of building required for sieving and storage (m^2)	90
Unit price of compost/kg (USD)	0.17
Unit price of compost (50 kg bag) (USD)	8.5

Table 5. NPV and IRR for the base scenario and sensitivity analysis under Model 1.

Parameter	Model 1-Processor		Model 1-Farmer	
	IRR 25 Years (%)	NPV ($)	IRR 30 Years	NPV ($)
Base scenario	39.16	119,504	7.05	−88.65
Inclusion of carbon credit	NA	NA	11.33	−57.52

Table 6. IRR and NPV for Sensitivity analysis under Model 1.

Parameter	Model 1-Processor		Model 1-Farmer	
	IRR 25 Years (%)	NPV ($)	IRR 30 Years (%)	NPV ($)
Selling/purchase price of seeds				
USD 0.05	47.26	174,383	Negative value *	−227.33
USD 0.16	Negative value *	−127,452	60.84	535.41
Price of crude oil				
USD 473/tonne	20.44	11,858	NA	NA
USD 1000/tonne	81.44	458,547	NA	NA

Table 6. *Cont.*

Parameter	Model 1-Processor		Model 1-Farmer	
	IRR 25 Years (%)	NPV ($)	IRR 30 Years (%)	NPV ($)
Seed yield				
0.55 tonnes/ha/year	NA	NA	Negative value *	−274.69
7.5 tonnes/ha/year	NA	NA	41.49	261.13
Price of compost				
USD 0.13	25.68	39,120	NA	NA
USD 0.25	50.81	199,889	NA	NA

* No result given in excel model because values are too extreme; NA—Not applicable for the scenario.

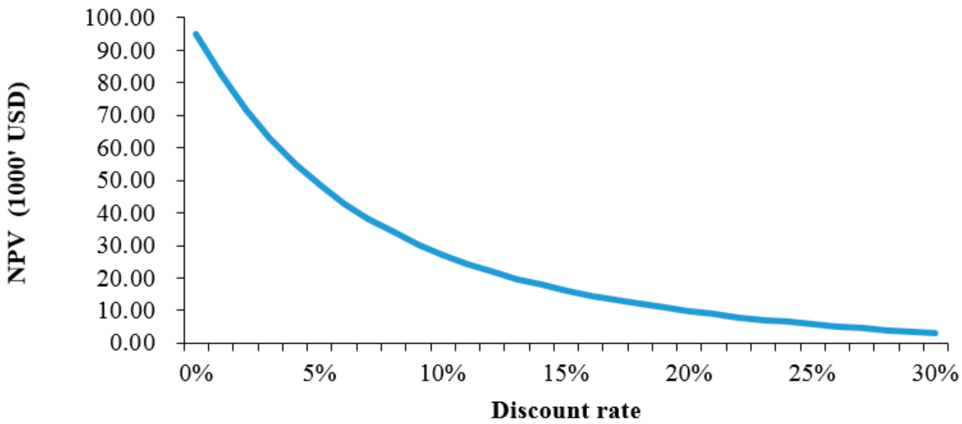

Figure 5. NPV curve for Model 1: Processors' perspective.

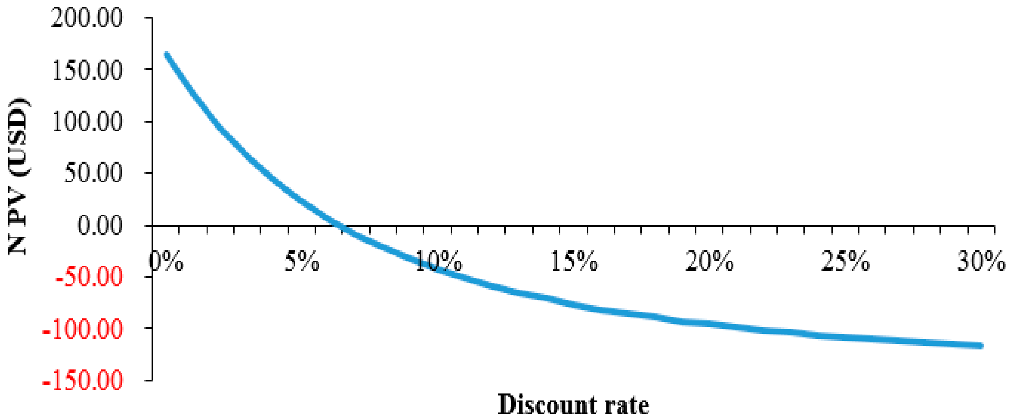

Figure 6. NPV curve for Model 1: farmers' perspective.

3.2. Technical and Cost Benefit Analysis of Model 2

This model builds on Model 1 with the substitution of exporting the crude jatropha oil with local utilisation of the oil and the by-products. The utilisation of the oil for electricity generation and soap production and the by-products for biogas and briquettes production was considered in this model. Six main scenarios under different matrix combinations for oil and by-products utilisation were therefore considered under this model. This has been demonstrated for rural electrification in some Sub-Saharan African countries [25], including some rural communities in Northern Ghana. Five diesel generators of 16 kW capacity with fuel consumption of 5.4 L/h which can run on pure jatropha oil would be required to generate 651,095 kWh of electricity from 219,744 L of oil annually (see Table 7).

Feed-in-tariff rate of $0.18/kWh [26] was considered for revenue generation from electricity production. The use of jatropha oil for soap production has been reported to be good and safe [8,27]. Model 2 therefore considered the utilisation of the filtered and residual oil for soap production. To produce 1 kg of soap, 2.77 L of oil, 2.07 L of water and 0.41 kg of caustic soda are required. Annual quantity of soap estimated at 88,756 kg is expected to be produced from 245,496 L of oil and 36,824 kg of caustic soda (see Table 8). A unit price of soap bar (180 g) at $1.5 was considered for revenue generation.

Table 7. Technical parameters and assumptions for electricity generation.

Parameter	Value
Electricity generation from jatropha oil	
Capacity of generator set @ 50 HZ, 1500 rev/min (kW)	16
Fuel consumption at 100% power ratings (litres/h)	5.4
Quantity of oil available (L)	219,744
Number of hours generator must operates based on fuel consumption rate	40,693.41
Number of generators required assuming operational hours of 8700 annually	5
Electricity generated (kWh)	651,095
Unit price of generator (USD)	4269
Lifespan of generator (years)	25
Feed in tariff rate (USD/kWh)	0.18
Electricity generation from biogas	
Generator rated power @ 50 HZ, 1500 rev/min (kW)	8
Fuel consumption @ 100% power ratings (m^3/kWh)	0.38
Quantity of methane available (m^3)	76,888
Electricity generated (kWh)	29,218
Number of hours generator must operate	3652.19
Number of generators required	1
Oil consumption (g/kWh)	2
Unit price of generator (USD)	7000
Lifespan of generator (years)	20
Feed in tariff rate (USD/kWh)	0.18
Size of building for housing biogas generator (m^2)	10

Table 8. Technical parameters and assumptions for soap production.

Parameter	Value
Quantity of oil required to produce 1 kg of soap (litres)	2.77
Quantity of water required to produce 1 kg of soap (litres)	2.07
Quantity of caustic soda required to produce 1 kg of soap (kg)	0.41
Quantity of oil available (tonnes)	205
Quantity of oil available (litres)	245,496
Quantity of soap produced from the available oil (kg)	88,756
Quantity of caustic soda required (kg)	36,824.44
Quantity of water required (litres)	184,122
Unit price of caustic soda per 25 kg (USD)	300
Capacity of soap mixing tanks (litres)	98
Number of soap mixing tanks required	3
Unit price of soap mixing tanks (USD)	2800
Capacity of manual cutting molds (kg)	32
Number of hours it takes for soap to harden in molds before removal	24
Number of manual soap cutting molds required	12
Unit price of manual soap cutting molds (USD)	375
Capacity of manual soap cutter per minute (kg)	1
Number of soap cutters required	1
Unit price of soap cutter (USD)	1895
Unit price of bath bomb press (USD)	275

Table 8. *Cont.*

Parameter	Value
Unit price of bath bomb molds (USD)	285
Capacity of drying tray (kg)	12
Number of hours it takes for soap to cure before packaging (hours)	336
Number of drying trays required	270
Unit cost per tray (USD)	25
Size of building required for soap production (m^2)	100
Unit price of soap bar (180 g in weight) (USD)	1.5

Utilisation of press cake for biogas production was also considered under Model 2. Annual quantities of bio-methane and bio-fertilizer expected to be generated from 387 tonnes of press cake were 80,935 m^3 and 106,728 kg, respectively. Two fixed dome digesters of capacity 25 m^3 each will be required to hold the press cake generated. Unit price of bio-fertilizer and bio-methane considered for revenue generation were \$0.19/kg and \$0.39/m^3, respectively. Table 9 presents the rest of the technical parameters considered for the biogas production. The use of biogas for electricity generation was also considered. Estimated annual electricity of 29,218 kWh is expected to be generated from 76,888 m^3 of biogas. This will require an 8 kW biogas generator with fuel consumption of 0.38 m^3/kWh (see Table 7). In situations where the press cake and fruit hulls are used for briquette production, 411 tonnes of briquette are expected to be generated from 693 tonnes of press cake and fruit hulls (see Table 10). Unit price of briquette was assumed to be \$0.12/kg.

Table 9. Technical parameters and Assumptions for biogas production.

Parameter	Value
Digester type	Fixed dome system
Density of jatropha press cake (kg/m^3)	1200
Volume of press cake (m^3/day)	0.88
Mixing ratio of press cake and water	1:1
Daily substrate input (m^3/day)	1.77
Retention time (days)	25
Digester volume (m^3)	44.14
Required digester volume for optimal gas production (m^3)	25
Number of biogas plant required	2
Operating temperature (°C)	30
Quantity of total solids available (Degradable material) (tonnes)	355.76
Quantity of gas generated (L) (350 L/kgTS)	124,515,468
Quantity of methane available (L) (65% of biogas)	80,935,054
Quantity of methane available assuming 5% losses (L)	76,888,301
Quantity of methane available (m^3)	76,888
Quantity of digestate generated (kg) (30% of feedstock)	106,728
Cost of Biogas plant per cubic meter (USD)	300
Lifespan of digester (years)	25
Unit price of bio methane per cubic meter	0.39
Unit price of bio fertilizer generated/kg	0.19

The cost-benefit analysis for this model was also done from two perspectives, similar to Model 1: processor and small holder farmer (out-grower). Scenarios 6 and 2 under this model had the lowest and highest investment cost of \$119,160 and \$128,359, respectively. Scenarios 1 and 6 had the lowest and highest annual operational cost of \$179,738 and \$588,033, respectively (see Figure 3). Investment and operational cost from the farmer's perspective were \$150 and \$90.81, respectively. Figure 4 presents streams of revenues generated from each of the scenarios under Model 2. At a discount rate of 18%, all the scenarios under this model had a positive NPV and IRR greater than the interest rate except Scenario 2 (see Table 11). This indicates that all the scenarios under this model are financially viable and confirms the assertion by [28] that valorisation of jatropha by-products might fundamentally increase the profitability of jatropha business ventures. Scenario 2 had the lowest NPV and IRR values of $48,280 and 23.90%, respectively. Even though all the scenarios considered under this model were financially viable for an investor/processor, financial viability from the perspective of the farmer was not achieved since NPV and IRR values of $−88.65 and 7.05% were estimated, respectively.

Table 10. Technical parameters and assumptions for briquette production.

Parameter	Value
Quantity of press cake and hulls available (tonnes)	693
Capacity of briquette machine (t/h)	0.18
Operational hours (h)	1750
Number of briquette machines required	2
Fraction in weight of cake that remains after compression	0.6
Quantity of briquettes produced per year (tonnes)	416
Quantity of briquette assuming 1% losses (tonnes)	411
Unit cost of briquette machine (USD)	1000
Power of motor of briquette machine (kW)	15
Capacity of carbonizer machine (t/h)	0.70
Unit price of Carbonizer machine (USD)	3000
Number of carbonizer machine required	1
Power of motor of carbonizer (kW)	1.5
Annual electricity consumption of briquette and carbonizer (kWh)	60,841.62
Lifespan of briquette and carbonizer (years)	20
Oil and lubrication charges (% of fuel cost)	2
Size of building required for briquetting (m^2)	100
unit price per kg of briquette (USD)	0.12
Unit price per bag of briquette (32 kg) (USD)	3.84

Critical variables identified for sensitivity analysis of Model 2 were discount rate, selling/purchase price of seeds, seed yield, feed in tariff rate and prices of biogas, bio-fertilizer, briquette and soap. Figure 7 presents variation of NPV as discount rate varies from 0% to 30%. It indicates that Scenario 2 is not financially viable at a discount rate >23.9% but the rest of the scenarios are financially viable for the range of discount rate considered. Financial viability can be achieved from the perspective of the farmer if the discount rate is ≤7%.

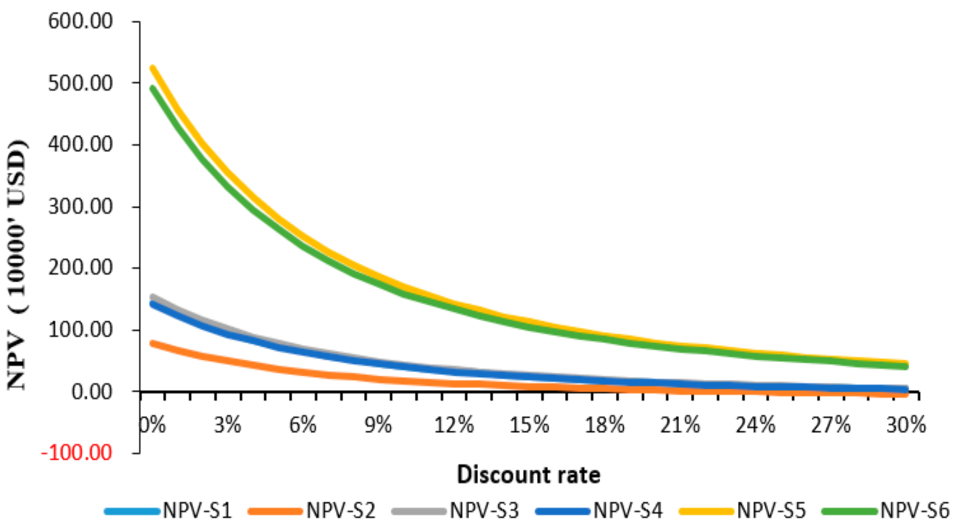

Figure 7. NPV curves for the six scenarios under Model 2.

Table 11. NPV and IRR for the base scenario and sensitivity analysis for the six scenarios under Model 2.

Parameter	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	IRR 25 Years (%)	NPV ($)	IRR 25 Years (%)	NPV ($)	IRR 25 Years (%)	NPV ($)	IRR 25 Years (%)	NPV ($)	IRR 25 Years (%)	NPV ($)	IRR 25 Years (%)	NPV ($)
Base Scenario	39.40	184,768	23.90	48,281	39.10	193,654	37.34	172,668	92.75	907,230	91.62	847,265
Sensitivity analysis												
Purchase price of seeds/kg												
USD 0.05	44.78	239,647	29.98	103,160	44.18	248,533	42.63	227,547	96.04	962,109	95.10	902,144
USD 0.16	8.19	−62,188	Negative value *	−198,675	10.37	−53,302	6.74	−74,288	76.89	660,274	74.78	600,309
Price of biogas/m^3												
USD 0.27	34.99	142,146	NA	NA	34.95	151,032	NA	NA	90.14	864,608	NA	NA
USD 0.51	43.60	227,389	NA	NA	43.07	236,276	NA	NA	95.31	949,851	NA	NA
Price of bio fertilizer/kg												
USD 0.13	36.29	154,482	20.28	17,995	36.17	163,368	NA	NA	90.90	876,944	NA	NA
USD 0.25	42.27	213,645	27.17	77,158	41.81	222,531	NA	NA	94.49	936,1066	NA	NA
Price of briquette/kg												
USD 0.08	NA	NA	NA	NA	36.40	165,666	28.05	83,967	91.04	879,241	85.81	758,564
USD 0.16	NA	NA	NA	NA	41.73	221,642	45.75	261,368	94.44	935,218	97.20	935,965
Feed-in-tariff rate(kWh)												
USD 0.23	53.25	332,669	39.91	202,819	52.19	341,555	50.99	320,569	NA	NA	NA	NA
Price of soap/180 g												
USD 1.1	28.86	86,710	10.94	−49,888	29.21	95,596	27.00	74,610	17.48	−3,893	7.78	−63,858
USD 1.95	49.43	289,805	35.12	153,207	48.58	298,691	47.22	277,705	145.3	1,932,243	146.7	1,872,278

* No result given in excel model because values are too extreme; NA—Not applicable for the scenario.

Sensitivity analysis on the selling/purchase price of seeds revealed that, at seed price of $0.05/kg, the projects are financially viable from the processors perspective for all the scenarios but not viable for farmer engaged as out-growers. The situation is vice versa when the purchase price of seeds was increased to $0.16/kg. Under this given seed price, only Scenarios 5 and 6 were considered to portray financially viability (see Table 11). Financial viability for both an investor/processor and a farmer was achieved when the purchase/selling price of seeds was $0.085/kg translating into a positive NPV for all the scenarios. A decrease in the price of soap to $1.1/180 g generated a negative NPV and IRR <25% for Scenarios 2, 5 and 6, since the bulk of the revenues for these scenarios were generated from the sale of soap.

3.3. Cost Benefit Analysis for Utilisation of Jatropha Oil

The models were built on a common farming model, which is an out-grower farming scheme. As described earlier, three cases were considered for the utilisation of jatropha oil under these models; export, electricity and soap production. This section of the study therefore sought to identify which of the cases of oil utilisation is financially viable and profitable under this farming model from the perspective of an investor/processor.

Utilisation of the oil for electricity production had the highest investment cost of $95,303 whereas soap production had the highest annual production cost of $496,402 (see Figure 8). The cost of producing a litre of jatropha oil was estimated at $0.48. This is lower than reported figures of $0.61–1.04/L [29]. The difference can be attributed to lower cost of labour and production cost in Ghana. Soap and electricity production had the highest and lowest unit profit of 1.96/kg and 0.01/kWh respectively (see Figure 9). Unit profit for export of oil was determined to be $0.03/L. The findings are lower than the reported profit of $0.21/L [18]. At a discount rate of 18%, NPV values for export, electricity and soap production under the out-grower farming scheme were estimated to be $−19,697, $−43,209 and $653,940 respectively. This indicates that utilisation of jatropha oil for soap production is the only profitable case for oil utilisation under the out-grower farming schemes. This confirms the assertion by [5] that utilisation of jatropha oil for soap making is the most profitable venture. The study further revealed that export of oil and electricity production is only profitable at oil price ≥$624/tonne and feed-in-tariff rate ≥$0.20/kWh.

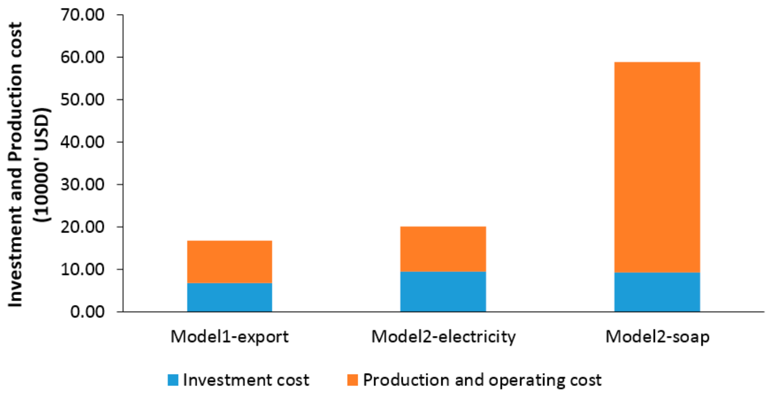

Figure 8. Investment and production cost for utilisation of oil.

3.4. Optimisation of Jatropha Oil and By-Products Utilisation

Three main cases for jatropha oil utilisation were considered in the developed models. This section of the study sought to optimise their use through profit maximisation. This was performed by taking into consideration the resources and amount of raw material used in the production of each unit, market availability and unit profit of each product as determined from the models. Table 12 presents the objective functions and constraints used in the optimisation of the oil.

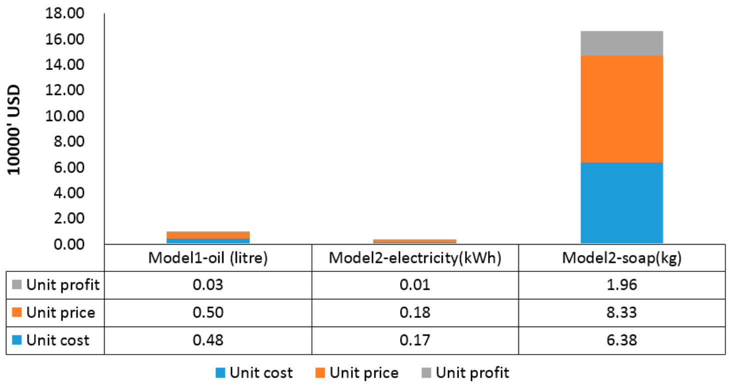

Figure 9. Unit price, cost and profit for utilisation of oil under the models.

Table 12. Objective function and constraints for the optimization.

Objective Function	Constraints
Utilisation of Oil	
$Z_1 = Maximize\ (P) = 0.03X_1 + 0.01X_2 + 1.96X_3$ where: $X_1 = Quantity\ of\ oil\ required\ for\ export\ (\text{L})$, $X_2 = Quantity\ of\ electricity\ required\ (\text{kWh})$ $X_3 = Quantity\ of\ soap\ required\ (\text{kg})$ $P = Maximum\ profit\ (\text{USD})$	$C_1 : X_1 + 0.34X_2 + 2.77X_3 \leq 219,744.43L$ $C_2 : X_1 \leq 131,846.66$ L $C_3 : X_2 \leq 651,094.61$ kWh $C_4 : X_3 \leq 62,129.45$ kg $C_5 : X_1, X_2, X_3 \geq 0$

Solving the linear equation using Simplex method yielded a maximum annual profit of $123,300. This required the production of 140,135 kWh of electricity and 62,129 kg of soap and export of none of the oil. Performing sensitivity analysis on the linear equation by increasing price of oil to $1000/tonne yielded a maximum profit of $138,726. This can be achieved at a projected export of 47,646 L of jatropha oil and production of 62,129 kg of soap. Decreasing the price of soap to $1.1/180 g generated a maximum profit of $7410 by producing 646,307 kWh of electricity. Purchase price of seeds is a very critical parameter in the models developed. Increasing the purchase price of seeds to $0.1/kg (recommended price as determined in the models) yielded a maximum profit of $109,129 which can be achieved by producing 62,129 kg of soap without export of the oil or its use for electricity generation.

4. Conclusions

The aim of this study was to develop techno-economic models for the production and optimised utilisation of jatropha oil and by-products under an out-grower farming scheme. The findings revealed that Model 1 was financially viable for an investor/processors' but not for a farmer engaged as an out-grower to cultivate and supply jatropha seeds at seed price of $0.07/kg. Financial viability was, however, achieved under Model 1 for both parties at seed price of $0.1/kg. All scenarios considered under Model 2 were financially viable for an investor/processor to the disadvantage of the farmer at seed price of $0.07/kg. Financial viability was, however, achieved for both the processor and farmer at a seed price of $0.085/kg. The findings indicate that valorisation of jatropha by-products and local utilisation of oil produce financial viability for jatropha production and processing ventures. The models are, however, sensitive to seed yield, market prices of crude jatropha oil, soap, biogas, compost, electricity and briquette. Utilisation of the oil for soap production was identified to be the only profitable case for oil utilisation in the base scenario in terms of NPV and IRR. However, export of the oil and its use for electricity production can only be profitable at oil price ≥$624/tonne and feed-in-tariff rate ≥$0.20/kWh, respectively. Optimising the utilisation of the oil resulted in an annual maximum profit of $123,300. This will be achieved at the production of 140,135 kWh of electricity and 62,129 kg of soap without the need to export any amount of the oil produced. The findings of the study indicate that jatropha production and utilization is not all gloomy as reported but with the adoption of the right business models in this study, it can provide sound economic benefits for both processors and farmers. The adaptation of these models can ensure sustainable production and utilization of Jatropha oil and by-products.

Author Contributions: I.O. conceived of the study, drafted the manuscript and participated in the sequence alignment. J.O.A. was involved in data analysis and contributed in the drafting of the manuscript. F.K. was involved in data analysis and participated in the drafting of the manuscript and in the sequence alignment. All authors read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. References for Technical Parameters, Assumptions and Cost Components Used in the Models

Parameter	Value	References
Plantation establishment		
Planting spacing	2 m by 2 m for jatropha plantation and 1.5 m within rows for jatropha hedges	[11,30]
Lifespan of jatropha plantation	30–50 years	[31]
Production start time (economic yield)	3 years	[4]
Plant yield per ha	minimum 0.55, average 3 and maximum 7.5 tonnes per ha	[4,5,32–37]
Small-holder farmers (seed production)		
Labour requirement for land preparation, planting weeding and pruning, harvesting and dehulling	-	[29,37]
Labour requirement for harvesting	40 kg of seeds per person per day	[4]
Cost for dehulling	10% of harvesting cost	[4]
Cost of labour per day	USD 7.2	[38]
Purchase price of seeds per kg	Minimum USD 0.05, average USD 0.07 and maximum of USD 0.16	[19]
General information		
Fuel cost per litre	USD 0.99	[39]
Electricity cost per kWh	USD 0.15	[26]
Cost of building per square meter	USD 90	[40]
Wages of workers	Calculated from daily minimum wage in Ghana-USD 2	[41]
Oil extraction		
Percentage composition of jatropha seeds, hulls, oil, press cake and residual oil	66%, 34%, 30.89%, 65.1% and 3.60% respectively	[38]
Price and technical parameters of jatropha de-huller	-	[42]
Price and technical parameters of oil screw press	-	[43]
Price and technical parameters of filtering unit	-	
Selling price of crude jatropha oil per tonne	Minimum 473 average 600 Maximum 1000	[11,44]

Biogas production		
Density of jatropha press cake	1200 kg/m^3	[45]
Sizing of biogas digester		[46]
Unit cost of digester per cubic meter	300	[38]
Quantity of gas generated from press cake	Press cake consist of 92% oTS and biogas generated is 350 L/KgoTS with 65% methane	[47]
Quantity of digestate generated	30% of feedstock	[48]
Price of bio-methane per cubic meter	Calculated from the relation that 1 m^3 of biogas is proportional to 0.6 m^3 of LPG gas, current price of LPG gas per kg USD 0.86 price of biogas is USD 0.39 per m^3	[38,46]
Price of bio-fertilizer kg	Price of bio-fertilizer is assumed to be 1/3 price of chemical fertilizer which is 100 Cedis per 50 kg bag	[38]
Briquette production		
Price and technical parameters of briquette machine		[49]
Price and technical parameters of carbonizing machine		[50]
Fraction of cake that remains after compression	0.6	[51]
Unit price per kg of briquette	USD 0.12 (calculated from average price of wood charcoal in Ghana)	[52]
Electricity generation		
Price and technical parameters of jatropha oil generator		[53]
Price and technical parameters of biogas generator		[54]
Feed in tariff rate	USD 0.18	[55]
Soap production		
Quantity of oil, caustic soda and water required to produce 1 kg of soap	2.77 L, 0.41 kg and 2.07 litters respectively	[30,56]
Price and technical parameters of soap mixing tanks		[57]
Price of caustic soda per 25 kg	USD 300	[58]
Price of manual cutting moulds (32 kg capacity)	USD 375	[59]
Price of soap manual cutter	USD 1895	[60]
Price of bath bomb press and moulds	USD 275 and 285 respectively	[61]
Unit price of drying trays (12 kg capacity)	USD 25	[62]
Period for curing	two weeks	[30]
Unit price of soap per 180 g	1.5 USD	[38]
Compost production		
Percentage volume of input materials that remains after composting	50%	[63]
Ratio of press cake to bulking agent	2:1	[64]
Conditions for optimal compost production: temperature, moisture content, C:N ratio, PH and oxygen concentration	48–65 °C, 50%–60%, 25–35:1, 6.5–8 and 10% respectively	[63,65]
Price and technical parameters of compost screen sieves	USD 1000	[66]
Price of monitoring devices (compost thermometer, ph meters and moisture meter)	USD 125	[67]

Exchange rate of GH₵3.5 to 1 USD was used.

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