KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEVELOPMENT OF TECHNO-ECONOMIC MODELS FOR OPTIMISED UTILISATION OF *JATROPHA CURCAS* LINNAEUS

BY

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CERTIFICATION

I hereby declare that this submission is my own work towards the MPhil and that, to the best of my knowledge; it contains no materials previously published by another person or material, which has been accepted for the award of any other degree of the university, except where acknowledgement has been made in the text.

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ABSTRACT

This study sought to develop techno-economic models for the production and optimised utilisation of jatropha oil and its by-products. Jatropha oil and press cake briquette were characterised for physico-chemical properties. Four models were developed based on business cases for jatropha production and processing. Model 1: large-scale plantation with export of oil. Model 2: large-scale plantation and utilisation of oil for electricity and soap production and by-products for biogas and briquette production. Model 3: out grower scheme with export of oil and utilisation of cake for compost. Model 4: out grower scheme with utilisation of oil and by-products as presented in model 2. Economic analyses of the models were performed using NPV and IRR. Linear programming models were developed based on outcomes of the models to optimise the use of jatropha oil and by-products through profit maximisation. Results from the study revealed average oil, press cake and residual oil content of 30.89%, 65.51% and 3.60% respectively. Physico-chemical properties of the oil revealed iron content (62 mg/kg), iodine number (93), flash point (213^{o}C), density (918 kg/m^3) and acid value (29.75 mgKOH/g). The findings suggest that using the oil directly in modified CI engine require thorough filtering to remove contaminants to recommended levels. Results of the physico-chemical assessment of the briquettes revealed moisture content (8% dry basis), ash content (4.64%) and calorific value (7,115.7 kcal/kg) which meet recommended briquette characteristics. Findings from the techno-economic models revealed that model 1 was not financially viable. All the scenarios considered under model 2 were financially viable. Models 3 and 4 were financially viable from the processors' perspective but not from the farmers'. Financial viability was achieved for both parties in models 3 and 4 at seed price of $0.1/kg and $0.085/kg respectively. Soap and biogas production were identified to be the most profitable use of oil and by-products respectively. The findings indicate that, valorisation of by-products and local

utilisation of Jatropha oil produce financial viability. Optimising the utilisation of the oil resulted in annual maximum profit of $147,865. This required production of 140,135 kWh of electricity and 62,129 kg of soap. Maximising the utilisation of by-products resulted in an annual profit of $22,220 by producing 46,133m^3 of biogas and 87,241 kg of compost.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The worldwide recognition of limits in the availability of major fossil energy sources and the rapidly rising energy prices have introduced a massive search for new energy sources for world economic development. The adverse impacts of escalating fuel prices despite the decrease in the international crude oil prices on the Ghanaian economy, coupled with the need to take action to combat climate change have led to national development agencies to look for alternative and environmentally friendly sources of energy. This led to the establishment of the Ghana Renewable Energy Act (Act 832) in 2011. The main objective of the RE Act is to provide for the development, management and utilisation of renewable energy sources for the production of heat and power in an efficient and environmentally sustainable manner.

Biofuel production has recently attracted much attention, with some anticipating substantial social and environmental benefits, while at the same time expecting sound profitability for investors. This has drawn comprehensive attention to Ghana and African countries as a whole for their abundant unexploited natural resources and relatively low production costs. A major motivation for embarking on biofuels, is a desire to promote sustainable economic development with significant social, environmental and economic returns, never ending marketing potential and poverty reduction in rural areas (Sawe and Shuman, 2014). Ghana's draft bioenergy policy of 2010 (Energy Commission, 2010) aims at the substitution of national petroleum fuels consumption with biofuel by 10% by 2020 and 20% by 2030. This target poses a huge challenge for decision makers to ensure that, promising innovative biofuel crops and processes are up-scaled in a short time span without compromising on poverty reduction and valuable ecosystems. Jatropha is one of the potential energy crops that can enable this target to be met in the stipulated time.

Jatropha curcas Linnaeus (Jatropha) also known as physic nut is found to be a potential alternative source of renewable energy. Jatropha belongs to the family *Euphorbiaceae.* It is a shrub which can reach a height of 5m, but can grow up to 10m under favourable conditions (Kumar and Sharma, 2008). It is claimed to be a vigorous drought and pest-tolerant plant that can grow on degraded lands even under harsh climatic conditions. It is easily established and grows very quickly with a gestation period of only a year. The shrub starts bearing fruit from the first year of planting but economic yield starts from the third year (van Dorp, 2013). If managed properly, Jatropha can produce 4-5 kg of seeds per tree from the 5th year onwards and has longevity of 40-50 years (Singh *et al*., 2008). Its cultivation and oil extraction contribute to sustainable development, poverty alleviation, combating of desertification and women empowerment in developing countries (Ofori-Boateng and
Lee, 2011). The major energy carriers from jatropha are the raw oil and its esters.
Jatropha has high oil content up to 40% seed yield but generally, it lies in the range of 30–35% (Heller *et al*., 1996). Jatropha oil, just like other vegetable oils can be used directly in modified diesel engines for automobile applications and electricity generation (Sheehan *et al*., 1998). The utility of jatropha oil and its esters as replacements for diesel fuel has been well documented by Kywe and Oo (2009). The oil can also be used for soap production. Without any further processing it can be used as a replacement for kerosene in lamps and lanterns which is predominantly used for rural lighting (Ofori-Boateng and Lee, 2011). The technologies for converting Jatropha into mainstream energy have mainly focused on mechanical and chemical processes concentrating on seed oil, however, it is a robust energy plant, which produces press-

cake, fruit hulls, and wood in addition to the seed oil. These are potential sources of additional energy carriers in a zero-waste bioenergy system. A number of technologies have been advanced to derive solid, liquid and gaseous energy carriers from Jatropha and its by-products. These include: trans-esterification gasification, briquetting, anaerobic digestion, pyrolysis and combustion. The technologies could optimise the energy value of Jatropha.

Current fuel prices and market conditions suggest that, jatropha biofuel production is not profitable in most cases considering the resources used. This has led to instances where the cultivation of the plant has been abandoned and the land used for food crop production. Muys *et al*. (2013) reported that, low returns have led to the abandonment of most commercial large-scale plantations in East Africa. In Ghana, a number of companies started Jatropha production in early 2008. However, uncertainties on the economic viability of the sector caused the failure of most of these companies later on (Boamah and Overå, 2016). Crucial issues for the economic performance of jatropha are the crop management systems, level of inputs and thereby yield and labour requirement, the price of jatropha seeds as well as the business model used which is either farmer centred or plantation model (van Eijck *et al*., 2012). Soto *et al*. (2013) indicated that valorisation of jatropha by-products might fundamentally increase jatropha profitability with jatropha production creating an alternative source of energy in remote areas highly dependent on energy imports. Since the by-products of jatropha are important for the economic feasibility of most biofuel developments, their uses need to be further diversified and supported with new technologies.

1.2 Problem Statement

Recent reports revealed that jatropha cultivation businesses did not go beyond the stage of the land acquisition and some few plantings. Until August 2012, out of 22 registered jatropha businesses, Biofuel Africa was reported to be the only company in Ghana that actually produced biofuel, but on a scale much smaller than planned (Boamah, 2014). Currently Smart Oil Limited is the only jatropha company in operation. Thus, there seems to be a systemic failure of business models for Jatropha production and processing in Ghana. This has also been reported in other Sub-Saharan African countries (Brüntrup *et al.*, 2013). The failure has been attributed to lack of agronomical knowledge (Wahl *et al*., 2009), unsustainable farming model (Sawe and Shuman, 2014) and non-valorisation of by-products (Soto *et al.*, 2013).

Van Eijck *et al*. (2013) reported that there are still many gaps in the economic data of Jatropha production and processing. Most studies focused on East and Southern Africa as well as India (Van Eijck *et al*., 2010) hence the need to undertake similar studies in West African countries, including Ghana.

1.3 Aim of the study

The aim of this study was therefore to develop techno-economic models for the production and optimised utilisation of jatropha oil and its by-products.

1.4 Specific objectives of the study

The specific objectives of the study were to:

1. Characterise jatropha oil and press-cake briquettes.
2. Determine the financial viability of jatropha production and processing under four business models using NPV and IRR.

3. Develop linear programming models to optimise the use of crude jatropha oil and its by-products.

1.5 Justification of the study

Technical and economic studies on jatropha production and processing are lacking in Ghana. Economic feasibility studies have however been undertaken across Africa (Romijn *et al*., 2014; FACT Foundation, 2010a; van Eijck *et al*., 2010; van Dorb, 2013; Alphen, 2012). These studies, however, did not take into consideration utilisation of jatropha by-products, variation of the various farming models and consideration of different end uses of the oil and how it affects the economic value of jatropha production and processing. The right technical and economic model for jatropha cultivation, it's processing, utilisation, and subsequent use of its by-products can greatly give confidence to stakeholders (farmers, Government, Investors and NGO's). These models when adopted by companies will help revamp jatropha production businesses in Ghana.

2. CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents the extent of jatropha production and processing in Ghana, as well as review of Jatropha economic feasibility studies across Africa. The value chain of Jatropha production and processing is explained. The concept of cost benefit analysis is further presented in this chapter.

2.2 General overview of Jatropha production

Liquid biofuels production has become an issue of concern in many African countries, as a result of large-scale establishment of biofuel feedstock plantation. These plantations present potential economic benefits, in terms of agricultural employment, as well as risks. Renner (2007) reported that Jatropha offers all the benefits of biofuels without the pitfalls which is to deliver oilseeds from degraded lands without affecting food crop production and diminishing natural resources. It has therefore been praised as an environmentally and economically sustainable biofuel feedstock (Renner, 2007). Grass (2009) indicated that Jatropha businesses were in their prime stage when the first Jatropha study was published in 2008. Failing Jatropha businesses werereported soon afterwards. Many practitioners and researchers declared the downfall of Jatropha (Openshaw, 2000; Kant and Wu, 2011). It became certain that cultivation was beyond both scientific understanding of its potential, particularly how it can grow on marginal lands (Fairless, 2007; Trabucco *et al*., 2010). The crops downfall was however not declared by all and is still being cultivated around the world (Lane, 2012). GEXSI (2008) reported a total of 242 Jatropha plantations worldwide as at 2008 which covered total estimated area of 900,000 hectares.

2.3 Jatropha production in Ghana: Successes and failures

Ghana has joined countries in the forefront of jatropha investments. Adam (2010) identified jatropha as one of the prominent feedstock for biofuel production in Ghana. In early 2008 when jatropha production in Ghana and other Sub-Saharan African countries gained prominence, large hectares of land were purchased by foreign and local investors for the purpose of producing jatropha for the local and foreign markets (Brüntrup *et al.,* 2013). Estimates of Jatropha developments in Ghana are mixed.

Schoneveld *et al*. (2010) reported thirteen commercial Jatropha companies in Ghana. These Jatropha businesses adopted large scale plantation schemes of more than 1,000 hectares. The companies altogether had access to estimated total land area of some 1,075,000 hectares. A more recent study by Antwi-Bediako *et al.* (2012) identified a total of seven Jatropha companies which collectively control an estimated 83,478 hectares of land.

Boamah (2014) reported that jatropha businesses in Ghana were not successful. Out of 22 registered jatropha businesses, Biofuel Africa was identified to be the only company in Ghana that was still in the business as at 2012. Brüntrup *et al*. (2013) revealed that a number of Jatropha companies have switched or want to switch to maize production. However, the extent is not clear. Possible reasons for the failure may be as a result of lack of agronomical knowledge which has been reported to be a major factor for the failure of jatropha farms (Wahl *et al.*, 2009). Another major reason for the failure of these companies can be attributed to the unsustainable farming model. Sawe and Shuman (2014) indicated that live fence of jatropha by small holder farmers and intercropping situations is the most socio-economically successful, and sustainable in Africa which is contrary to the farming models used by the Jatropha companies in Ghana. The absence of effective utilisation of jatropha byproducts (fruit hulls, press cake and residual oil) may be a reason for the total failure of most of these companies. Soto *et al.* (2013) indicated that, the valorisation of jatropha by-products may increase jatropha profitability. There is however no indication in literature that these companies added any commercial value to its byproducts in other to create other avenues for income generation apart from the sale of the crude jatropha oil. Non-availability of local market and most importantly nonprofitability of the business models in use might have fundamentally accounted for the systematic failures of these companies.

Despite the failure of most of these companies, there has been some success stories. The United Nation Department of Economic and Social Affairs (2007) identified a number of jatropha projects some of which include: Ghana Rural Enterprise/DieselSubstitution Project. This project was undertaken with support from the United Nation Development Programme (UNDP) by the Kumasi Institute of Technology and

Environment (KITE) as well as Kwame Nkrumah University of Science and

Technology (KNUST). The project championed the adaptation and use of the MultiFunctional Platform (MFP) and experimental analysis of jatropha oil. Based on the outcomes of the project, it was concluded that the best option for Jatropha businesses in rural areas is the utilisation of the oil in unmodified stationary diesel engines. This has been demonstrated successfully in Mali by Malifolke centre. KITE in 2004 also demonstrated a similar successful pilot MFP in Yaakrom community in the BrongAhafo region. Ofori-Boateng and Lee (2011) reported that women into shea butter production in the northern region use raw jatropha oil in place of diesel for their Multi-Functional Platforms (MFPs). This comprised of shea butter press, dehuller and mill. This was done primarily to empower women in rural Ghana in the area of job creation. *Busunu*, a community in the northern region also used raw jatropha oil in diesel engine for electricity generation, however, the community experienced some problems as a result of inconsistent supply of jatropha seeds.

2.4 Jatropha Production

Jatropha curcas Linnaeus (physic nut) shown in Figure 2.1 is in the family of spurges (Euphorbiaceae). It is a small tree which averagely grows to a height of about 3 to 5 meters (Carels *et al.*, 2009). Optimal soil condition for its growth is well drained sandy soil with good aeration (Heller, 1996). It has been reported that, the shrub grows well on marginal lands. However, sufficient quantities of nutrient must be available for the plants growth in other to obtain commercially viable yields. An annual mean temperature between 20 to 28°C and at least annual precipitation of 300 mm are required for the plants growth (Orwa *et al*. 2009). The plant is propagated by planting of seedlings, direct seeding and by stem cuttings and truncheons.

Figure 2.1: Jatropha curcas L.

Source: Mawire, 2008

2.4.1 Jatropha production schemes and models

It is often argued that for jatropha to fulfil its promise of contributing to sustainable rural development its cultivation must be small in scale, inclusive and communitybased (FAO, 2010; Achten *et al.*, 2009). Among 42 projects surveyed by Wahl *et al.* (2012) in Africa, the most prevalent production scheme is by plantation which represents (50%), out grower (21.4%) and a combination of both schemes (28.6%). Jatropha production and processing schemes emerging in Africa include; large scale plantation contracting small holders as out-grower. A typical example has been reported by Sawe and Shuman (2014) in Tanzania and Mali. Another production model is Contracted small scale farmers producing for private Organizations/ Companies without farms. Independent small-scale farmers (some organized in associations or cooperatives) locally producing, processing and utilizing oil locally has also been reported in Tanzania (Flytech Tanzania, 2013) and Ghana (OforiBoateng and Lee, 2011). German *et al.* (2011) reported that plantation scheme is more efficient in terms of production and also creating employment and building rural infrastructures. In this regard, access to land and cost become critical issues. Land has to be acquired in plantation schemes whiles out grower schemes requires farmers to cultivate on their own lands. Due to environmental risks posed by plantations, it has been reported to be controversial and may become environmental risk in the long run (FAO, 2010). Jatropha can either be cultivated as a single crop (mono-cropping) or in combination with other crops (intercropping) on plantation. Intercropping situations enable farmers to generate income during the first and second years of the plants growth when its cultivation does not generate enough revenue. Both cropping strategies may help contribute to energy and local food supply. The choice of a cropping method affects planting density of jatropha. Wahl *et al.* (2012) reported an average planting densities of 2,090 trees per hectare for mono cropping. Intercropping situations however requires lower planting densities. FAO (2010) reported that wide spacing of Jatropha trees may result in higher yield per tree because of less competition between individual trees, however, yield per hectare might decline.

2.4.2 Business case for Jatropha production and processing

Generally, every viable business model is highly dependent on its domestic and international target markets as well as its value-chain configuration. Adaptation to local specifics and needs are critical parameters for a viable Jatropha business model. Consistent and stable feedstock production has been identified as the most important parameter for a viable and successful Jatropha business model. This helps to reliably meet customers' needs and also provide consistent income generation avenue for local farmers. Jatropha commercial cultivation is however not optimised and its opportunity risk is not fully understood (Jongschaap *et al*., 2007; GTZ 2009). Domestication and commercial cultivation of the plant have not been long and therefore the best agricultural practices, yields and long term performance are not fully known (Silip *et al*., 2010). Furthermore, information on economic performance of the plant is scanty (FAO 2010; Borman *et al*., 2012). Based on these challenges, creating a business case from Jatropha without doubt is a difficult task. FAO (2010) identified the most important cost categories for commercial Jatropha cultivation to be: land acquisition, plant establishment, labour, plant nutrition, pest and disease management and irrigation. Yield per hectare in terms of quantity and quality is the most decisive parameter in terms of the output side.

2.5 Review of economic feasibility studies on jatropha production and processing

Several studies in different African countries have been conducted on the financial viability and socio-economic impact of different business models for jatropha production and processing.

Romijn *et al*. (2014) in their study on Economic and Social Sustainability Performance of Jatropha in Tanzania, Mali and Mozambique indicated a weak business case for Jatropha as at 2012. Due to higher capital cost in Jatropha plantation coupled with low seed yield, inefficient oil pressing and inadequate utilisation of byproducts, Jatropha plantations were identified to be unviable. However, temporal considerable employment was generated by these projects. Due to non-economic viability most of these projects were closed down. The study concluded that, cultivation of Jatropha as hedge plant in poor rural areas without alternative income generation opportunity is the most profitable. This conclusion has been buttressed by van Eijck *et al*. (2013).

The study by FACT Foundation (2010a) on Jatropha, retrospective and future development based on the outcomes of studies in Mali, Mozambique, Honduras, India and Kenya concluded that Jatropha cultivation is not profitable in a low-input scenario. This is due to the fact that yields are too low because very small quantities of fertilizer are applied. In a high-input scenario, the revenues are not high enough to cover the costs, and losses occur especially in the first years. On the basis of a 10-year investment, no or very low earnings can be obtained. The main problem observed by FACT Foundation in these studies is that most projections were based on a combination of assumptions (including yields, growth on marginal soils, low inputs), some of which were individually right, but they were wrongfully assumed to be true in combination. The study further indicated that, the only profitable business case is where farmers are planting Jatropha as hedges which are in line with the conclusion by van Eijck *et al.* (2010). Requirements that could make Jatropha feasible include low wages, a lack of profitable alternative crops, relatively fertile land and high market prices for seeds or oil. An interesting observation is that a carbon credit project would give additional benefits of USD 0.02 per kg of seeds, based on the use of the seedcake for biogas production under a CDM scheme. Biogas production itself would give additional benefits of USD 0.04 per kg of seeds (Van Dorp, 2013).

A comprehensive study on economic viability of jatropha production and processing was carried out by Van Eijck *et al*. (2010). The study reported that most studies focus on East and Southern Africa as well as India. CBAs (Cost-Benefit Analyses) have been undertaken for smallholders, mostly for small-scale Jatropha plantations, while some studies were done on intercropping and hedges. However, these studies have no specific reference to business organisation and sizes of production. The study presented some best estimates for the expected financial profitability of a large centralized plantation

setup and a decentralized out grower model with one (or a few) central oil processor(s). For the out grower model intermediate input scenario (weeding, fertilizer, pesticide application and pruning) and low input scenario (no irrigation and no fertilizer) were considered. The main findings for the out grower model was that; the estimated financial profitability was bad for the seed growers even at relatively good seed market price of $0.14/kg. The CBA generated IRR's of
5.3%-8.9% with pay back periods of 16 to 20 years for the small holder farmers.

Comparing the IRR's to a discount rate of 6.5% implies non-viability over a 20-year period. The intermediate input scenario performs even worse than the low input scenario due to the fact that revenues from higher seed yield did not compensate for the extra cost in fertilizer and irrigation application. The results of the CBA for the processors generated Payback period of 12 to 13 years and IRR of 13.4% for the low input scenario. The NPV for the processor looks high in absolute terms, but is poor when seen in relation to the amount of required investment. The results for the small holders were marginal in this scenario. For the intermediate scenario the best IRR for the processor was 17.2% but farmers in this scenario are expected to make a loss which makes this scenario not feasible.

Despite the reported financial non-viability of Jatropha production, Alphen (2012) in a study on sustainably developed biofuel from Jatropha Production in Cameroon concluded that plantation model is financially feasible even including a 20% uncertainty margin. This finding is contrary to the study by Romijn *et al*. (2014). This seems to suggest that Jatropha economic viability might be country specific. The study further indicated that plantation model is the most expensive model which is in line with the assertion by Romijn *et al*. (2014).

Van Eijck *et al*. (2013) found that there are still many gaps in the economic data. The reliability of the CBA technique highly depends on accurate estimations of the expected cash flows. The study identified two main problems in Cost Benefit Analysis (CBA) of Jatropha in literature. First, seed yield estimates were either too low or too high, leading to overly optimistic or overly pessimistic CBA outcomes. Secondly, opportunity cost of land, labour and other resources were not taken into consideration in these studies. Also, economic data on cost of crude Jatropha oil and biodiesel are scarce in Africa since commercial production of oil just begun. The study concluded that economic viability of Jatropha production and processing can be achieved through finding higher value use of by-products. Furthermore, developing high yield seed variety, efficient oil pressing and optimising cultivating practices can help contribute to economic viability of Jatropha. The study further concluded that projects that link seed production and local processing and utilisation of the oil are likely to achieve financial viability than non-local ones. A typical example is the FACT project in Mozambique. The study also concluded that the business case for processors who source from out growers also remains largely unproven. At estimated price of $1.20 per litre of Jatropha oil, it is still expensive. Jatropha oil production becomes economically feasible under the condition that its production cost is lower than the diesel price.

The study on economic feasibility of jatropha production by Van Dorb (2013) concluded that based on a limited number of studies on the economic feasibility of Jatropha production for smallholders (mainly focusing on East Africa). It is clear that Jatropha production is not a very profitable business case. The only economically viable business case is the planting of Jatropha as hedges. Some of these studies have shortcomings and the conclusions on economic feasibility are very much dependent on local circumstances, including the level of wages, availability of profitable alternative crops, land fertility and market prices for seeds or oil. The study further concluded that the studies are very context-specific and cannot be extrapolated to other situations.

2.6 Jatropha value chain

The main product from Jatropha is the non-edible seed oil, which can be used as feedstock for biodiesel production and directly for bio-kerosene and as transportation and machinery fuel (Bailis and Baka, 2010). Besides its most prominent uses, the plant as a whole and the oil provide other products, which include: soap, fuel for cooking, inputs for cosmetics, erosion control, livestock barrier and green manure fuelwood, just to mention a few (Kumar and Sharma 2008; FAO, 2010). Valuable byproducts such as a press cake, pruning material and seed husks can be used for composting and fertilisation and feedstock for biogas production. A schematic illustration of the valorisation of jatropha by-products is shown in Figure 2.2. Jatropha fruit is made up of the outer shell and seeds. Figure 2.3 presents the various composition of jatropha fruits and seeds. Averagely, Jatropha fruits are 2.5 cm long and ovoid in shape. Each fruit contains about 2 to 3 seeds and nearly 400-425 fruits per kg and 1,500-1,600 seeds per kg weight (Singh *et al*., 2008). From Figure 2.3 dry jatropha fruit contains about 37.5% fruit hulls and 60-65% seed by weight (Vyas and Singh, 2007). The seed consist of about 58% kernel and 42% seed husk (Singh *et al*., 2008; Abreu, 2008).

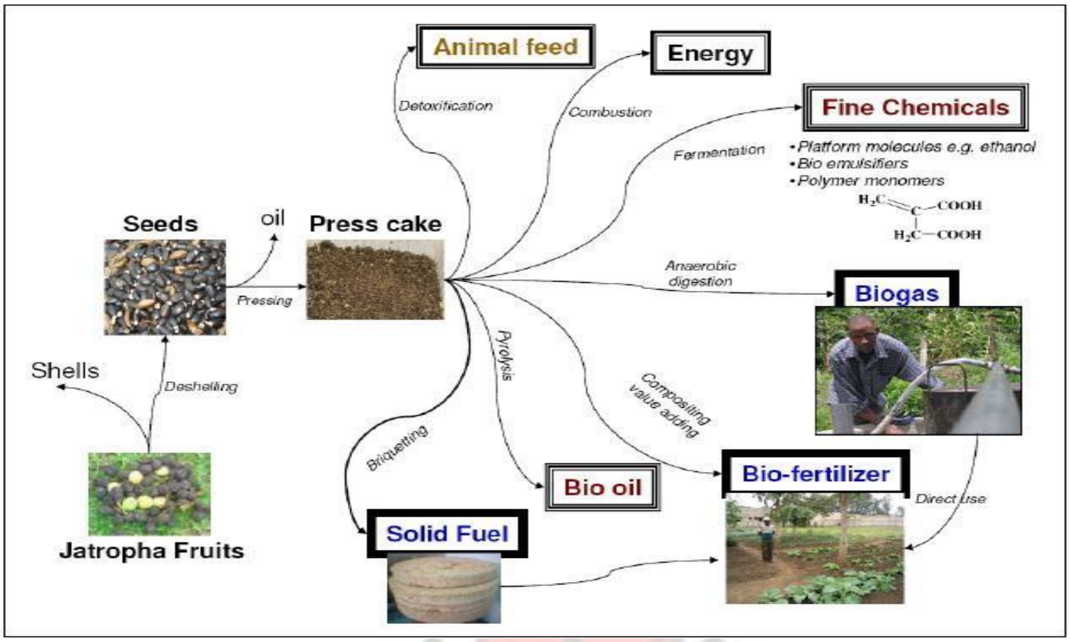


Figure 2.2: The valorisation of Jatropha press cake for bio refinery potentials

Source: Mkoma and Mabiki (2011)

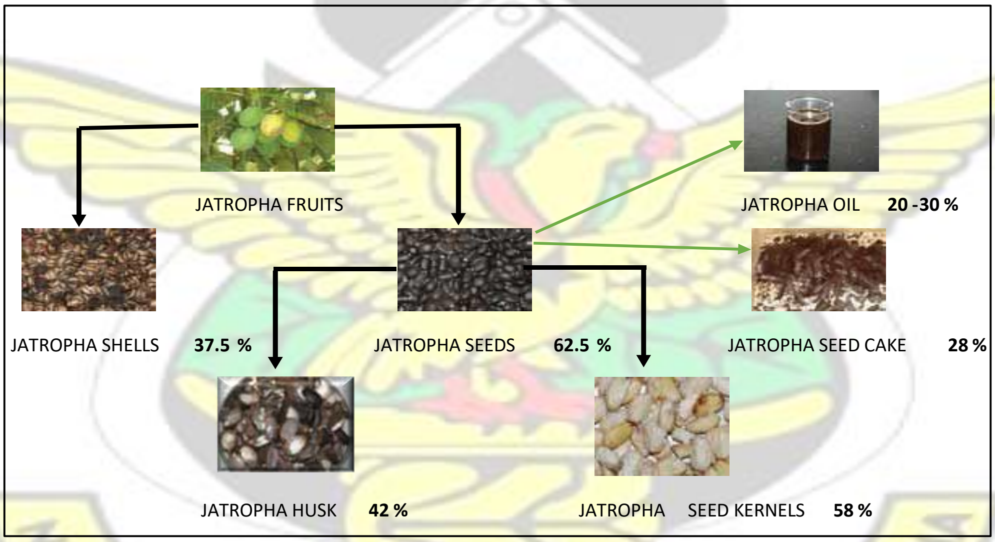


Figure 2.3: Composition of Jatropha fruit and seeds

Source: Abreu (2008)

2.6.1 Jatropha seed yield and oil content

Reported Jatropha yield in literature are largely not consistent. Reported higher yield may be due to extrapolation of measurements taken from single, high-yielding elderly trees (Jongschaap *et al*., 2007). Table 2.1 presents Jatropha seed yield figures reported in literature. These yield figures are mostly accompanied by little or no information about soil fertility, genetic provenance, plant spacing, propagation method, rainfall and pruning regime. These factors however have significant effects on the yield (Heller, 1996).

Table 2.1: Jatropha seed yield

Yield	Condition	Source
1. 0.1-8t/ha	N/A	Heller,1996
2. 5 t/ha	High rainfall and optimal management	Achten *et al.*, 2008
3. 0.4-12 t/ha	N/A	Openshaw, 2000
4. 0.2-2 kg/tree	N/A	Francis *et al.*, 2005
5. 6-7 t/ha	High rainfall and optimal management	Ghosh *et al.*, 2007
6. 7.8 t/ha	N/A	Jongschaap *et al.*, 2007
7. 0.3 – 5.2 kg/tree	N/A	GTZ, 2009
8. 1-4t/ha	Intercropped situation	Van Dorb, 2013
9. 0.1-1kg/tree	Hedges	Van Dorb, 2013

N/A- Not Available

Seed oil is the primary product from Jatropha, this makes oil yield the most critical issue in its cultivation. Oil yield is a function of seed yield and oil content of seeds. Heller (1996) reported oil yield between 18.4-42.3% and 17-18% by Singh *et al*. (2008), 30% by Abreu (2008). Jongschaap *et al*. (2007) reported that oil content varies between 23 and 39%. Figures 2.4 and 2.5 shows jatropha fruits and seeds respectively.

Figure 2.4: Jatropha fruits

Figure 2.5: Jatropha seed

Source: Van Peer, 2010

2.6.2 Extraction of jatropha oil

Four main basic methods for extracting Jatropha and vegetable oils in general from seeds and fruits have been progressed (Shahidi, 2005). The first method is the basic wet process in which the oil-bearing material is boiled in water leading to a partial separation of oil, which is then skimmed. The second is the cage-type press in which pressure is put on a stationary mass by levers, screw jacks or hydraulic cylinders and the vegetable oil flows from the compressed mass to collecting rings below. Both these methods are more or less inefficient and out of date. The third and fourth method are mechanical screw press and solvent extraction. Mechanical pressing and solvent extraction are the most commonly used methods for commercial oil extraction of jatropha. Screw pressing is used for oil recovery up to 90-95%, while solvent extraction is capable of extracting 99% (Bredeson, 1982).

2.6.3 Properties of jatropha oil

The quality of Jatropha oil is a very important parameter for assessing its suitability for biodiesel production and for direct use. The physical and chemical properties of Jatropha oil can vary based on environment and genetic interaction, seed size, weight and oil content as well as maturity of the fruits, which can affect the fatty acid composition of the oil. Extraction processes and storage conditions can further affect oil quality (Kratzeisen and Müller, 2009, cited by Achten , 2008). Crude jatropha oil is relatively viscous. It is low in free fatty acids, which improves its storability, though it's high unsaturated oleic and linoleic acids make it prone to oxidation during storage. Table 2.2 indicates characteristics of jatropha oil compared to diesel fuel.

Table 2.2: Comparison of the characteristics of jatropha oil and diesel fuel

Parameter	**Diesel oil**	**Jatropha oil**
Density kg/l (15/40 ^oC)	0.84-0.85	0.91-0.92

Cold solidifying point (^oC)	-14.0	2.0
Flash point (^oC)	80	110-240
Cetane number	47.8	51.0
Sulphur (%)	1.0-1.2	0.13

Source: Kratzeisen and Müller (2009)

2.6.4 Jatropha fruit hulls

The first stage of oil extraction is to mechanically remove the hull from the fruits. About one tonne of hulls can be obtained from one hectare and this material can be used as a source of energy. The chemical analysis of jatropha fruit hulls has been to consist of 34%, 10% and 12% cellulose, hemicellulose and lignin, respectively (Singh *et al*., 2008, Abreu, 2008). Singh *et al*. (2008) reported volatile ash, fixed carbon and volatile matter of the hulls to be 5%, 16% and 69% respectively. The results indicate that jatropha fruit hulls have very high ash content which influence the conversion technology to be used (Jingura *et al*., 2010). The calorific value of the hulls is between 16-17 MJ/kg (Kratzeisen and Müller, 2009). Abreu (2008) reported calorific value of 18.1MJ/kg, 11.1 MJ/kg by Sotolongo *et al*. (2009) and thus similar to wood, which is a main energy source in developing countries. A number of conversion technologies for fruit hulls to energy have been studied. These include: briquetting and pyrolysis (Singh *et al*., 2008), bio-methanation (Sotolongo *et al*., 2009) and gasification (Brittaine and Lutaladio, 2010).

2.6.5 Jatropha press cake

After extraction, about 50-75% of the weight of seeds remains as press-cake (Staubmann *et al*., 1997; Singh *et al*., 2008). This cake contains mainly proteins and carbohydrates. Depending on extraction type and efficiencies the press cake can contain about 9-12% oil by weight. The gross energy content of the press cake is about 18.2 MJ/kg (Achten *et al*., 2008), however, the oil content influences the calorific value.

Press cake has 94% total solids, out of which 93% is volatile solids. Jatropha seed cake is high in protein 58.1% by weight compared to soya meal's 48% (Barbee 2012). Due to its toxicity utilization of the cake as livestock feed is not possible. Removal of the toxins is however not commercially viable. The cake is also a good source of bio-fertilizer due to its high nitrogen content which is better than other organic fertilizers (Barbee, 2012). Jatropha press cake can be utilised effectively through the following: bio-methanation, briquetting and composting.

2.6.5.1 Biogas production from jatropha press cake

The press-cake is high in organic matter and has good potential for biogas production. Biogas is used for cooking and lighting. It has also been utilised for electricity production when larger volumes are generated. Biogas mainly consists of methane (CH_4) and carbon dioxide (CO_2) in a ratio of 60-40% and a net calorific value of about 20 MJ/m^3 (Fact foundation, 2010b). Biogas production from press cake through anaerobic digestion has been demonstrated (Singh *et al.*, 2008; Staubman *et al.*, 1997; Radhakrishma, 2007). Singh *et al.* (2008) observed that biogas production from jatropha press-cake was about 60% higher than that from cattle dung and contained 66% methane. Phosphorus, nitrogen and potassium levels have been shown to increase during the fermentation process. This presents the need to use the effluent as organic fertilizer for crop production.

2.6.5.2 Production of Briquette from jatropha press cake

Briquetting is the process of compacting loose biomass material to increase its density. Even though the press cake already is a pressed product, increase in its density through briquetting can significantly increase its energy content per kg. A low pressure briquetting machine operates in a similar way as a screw press. The press cake is compressed again to increase its density. A binding agent like starch may also be added during the compaction process to increase the cohesive force between the press cake particles. This enhances compaction for a low pressure compaction system. The main disadvantage of briquettes from fresh press cake is that a lot of smoke is emitted during combustion. A more preferable second option is to turn the press cake into charcoal briquette. This increases the calorific value and significantly decrease the quantity of smoke produced during combustion. About 60% of the weight of a press cake briquette will remain when processed into a charcoal briquette (Fact Foundation, 2010b).

2.6.5.3 Utilisation of Jatropha press cake as fertilizer

Jatropha oil cake is rich in phosphorous (1.4%) and potassium (1.3%) and a high nitrogen content of up to 6.48% which makes it suitable to be used for maintaining soil fertility (Jayasingh, 2003; Kumar and Sharma, 2008). Jatropha press cake is being used in many areas of the world as a fertilizer but literature and data regarding the efficacy of improving crop yields or conditioning soil is limited. A study by Ghosh *et al*. (2007) revealed that, yields of *Jatropha curcas* have been shown to increase up to 120% due to Jatropha seed cake application when applied at optimal rates and in optimal conditions. Table 2.3 shows the nutritional content of Jatropha seed cake compared to other organic fertilizer. From the table, it can be seen that, the nutrient potential of Jatropha seed cake makes it a potentially precious resource. Numerous studies have, however, shown that the toxic elements of the seed cake and oil are significant and there is concern about the environmental consequences of introducing toxins into the soil (Barbee, 2012).

Table 2.3: Comparison of nutrient content of jatropha seed cake and other organic fertilizers

Organic fertilizer type	**N**	**P**	**K**
Cattle manure (fresh)	0.29	0.25	0.1
Chicken manure (fresh)	1.6	1.0-1.5	0.6-1.0

Blood meal	15	0	0
Sheep and goat manure (fresh)	0.55	0.6	0.3
Banana residues (ash)	1.75	0.75	0.5
Duck manure (fresh)	1.12	1.44	0.6
Jatropha seed cake (non-composted)	**3.2-4.4**	**1.4-2.1**	**1.2-1.7**

Source: Barbee (2012)

2.6.5.4 Composting of jatropha press cake

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 products mentioned (Barbee, 2012). Composting has been shown to reduce the toxicity and oil content of the cake (Chaturvedi and Kumar, 2012). Composted jatropha cake has a balanced composition of nitrogen (2.95%), phosphorous (0.83%) and Potassium (1%) (Chaturvedi and Kumar, 2012). The use of composted jatropha press cake has been shown to significantly enhance the yield of tomato along with improvements in morphological parameters (Chaturvedi and Kumar, 2012).

2.6.6 Utilisation of Jatropha oil

Jatropha oil can be exported or utilised domestically for several purposes. Demand for Jatropha oil in Ghana and other African countries is currently limited. However, demand is expected to increase when the price is competitive with diesel fuel. As indicated earlier, jatropha oil can be used as fuel for transport, energy generation, cooking or lighting, and for soap making. Demand for large-scale electricity production from the crude oil is also currently been explored. Jatropha oil has also been found to control cotton bollworm and sorghum stem borers (Gubitz *et al*., 1999) and as insecticide, molluscicide, fungicide and nematicide (Achten *et al*., 2008).

2.6.6.1 Jatropha oil as feedstock for biodiesel production

Biodiesel production from jatropha and other vegetable oil is a chemical process whereby the oil molecules (triglycerides) are cut to pieces and connected to methanol molecules to form the jatropha methyl ester. Sodium hydroxide is normally used as an alkali to speed up the reaction. Apart from biodiesel, glycerine is generated as a byproduct. The reaction also requires alcohol and for cost and technical efficiencies methanol is normally used. Biodiesel may be used as partial blends (e.g. 5 percent biodiesel or B5) with mineral diesel or as complete replacements (B100) for mineral diesel (Brittaine and Lutaladio, 2010).

2.6.6.2 The use of pure jatropha oil in modified engines

Jatropha oil may be used directly in modified diesel engines, without converting it into biodiesel. This has been demonstrated with static diesel engines for rural electrification in some sub-Saharan African countries (Dimpl and Blunck, 2011). The main problem is its high viscosity compared to diesel fuel. This is, however, not a challenge in tropical countries such as Ghana due to high temperatures. Pure jatropha oil can be used in specially designed engines, such as the Indirect-injection engines, Two-tank system, and Single-tank vegetable injection systems.

2.6.6.3 Soap Production

Soap production from Jatropha oil has been reported to be profitable than the use of the oil for energy generation. This allows for reduction in the production cost and quality requirement of the oil as compared to biodiesel production. This process also create employment by involving more people in the production process. Soap production process is simple; the only problem is unavailability of caustic soda. Locally available materials such as cocoa pod ash can be used in place of the caustic soda in rural areas. However, this may affect the final quality of the soap. In most areas soap from Jatropha oil has fetched higher price than some industrial soap in the market owing to its whitish colour and perceived medical properties due to the poisonous substance in the soap (Nielson *et al*., 2012). This has, however, led to concerns over the safety of Jatropha soap. Vollner (2011) reported that recent test of Jatropha soap in Germany indicates that it meets all the government regulation for cosmetic soap. The soap production process involves addition of sodium hydroxide (caustic soda) solution to the oil. Due to the simplicity of the process, it has made soap production a viable small scale business appropriate in the rural areas. Henning (2004) reported that about 4.7 kg of soap can be produced from 13 litres of jatropha oil in only five hours.

2.7 The concept of Cost Benefit Analysis (CBA)

In this section of the review, features of cost benefit analysis are explained. Economic feasibility is determined by evaluating the financial net benefits of the production of a certain commodity or service. A CBA is an economic and financial appraisal tool which is used to calculate a project's profitability. It is mostly used when a project involves streams of cost and benefit over time (20 years is usually taken as the maximum) and a choice has to be made between a number of projects (ICRA, 2015).

2.7.1 Forms of Cost Benefit Analysis (CBA)

There are two major forms of conducting CBA: Financial or economic. A financial CBA is conducted from the perspective of an individual or a group involved directly in the project. Only cost and benefits generated in the projects are taken into consideration. The external effects of the projects (externalities) which can either be positive (favourable) or negative (unfavourable) are not taken into consideration in this analysis. A financial CBA analysis is therefore simple to calculate. A broader perspective of society is taken into account in economic CBA. All costs and benefits including externalities are taken into consideration in this analysis. Moreover, shadow pricing of goods and services (the price of goods to society), not the real prices, are used in the analysis. Economic CBA is more important in environmental projects, because it focuses on the value of the environment to society (Chowdhury and Kirkpatrick, 1994).

2.7.2 Characteristics of cost benefit analysis

2.7.2.1 Costs and Benefits

Costs which include investment is defined as the intended or unintended negative effects of a project while benefits are the intended or unintended positive effects of a project. Unintended costs and benefits (externalities) are not taken into consideration in many CBAs. This, therefore, may show only part of the picture and may lead to wrong decisions. Externalities play a very important role in CBA. This refer to the changes of livelihood of society as a result of the project. However, the project does not receive or pay any financial compensation (ICRA, 2015).

2.7.2.2 Financial flows

The profitability of a project covers only cash-inflows and cash-outflows attributable to activities of the project. Depreciation is therefore not taken into consideration in CBA as it does not involve cash payment (ICRA, 2015). This is because capital goods such as buildings, cars, and machineries are taken into consideration in two cash flows: investments and operation and maintenance cost therefore including depreciation will be double counting. In CBA, taxes may either be excluded (profitability before tax) or included (profitability after tax). Cash flows related to funding (credit) are not taken into account. In this way, the profitability reflects the efficiency of the project itself, which can then be compared with alternative uses of the investment.

2.7.3 Decision criteria for CBA

The Net Present Value (NPV) and the Internal Rate of Return (IRR) are the most commonly used decision criteria of CBA. Less used is the Benefit-Cost Ratio (BCR) and Pay back periods.

2.7.3.1 Net Present Value (NPV)

This is the difference between the present value of cash inflows and the present value of cash outflows. This is used to analyse the profitability of a project. It compares the value of a dollar today to the value of that same dollar in the future, taking into account returns and inflation. The NPV is the sum of the discounted net cash flows of a project. It represents the present amount of the net benefits flow generated by the investment expressed in one single value. Equation 1 is used in calculating the NPV.

$$NPV = \sum_{t=0}^{n} a_{t} s_{t} = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n} \ldots . Equation\ (1)$$

Where S_t is the balance of cash flow at time t and a_t is the financial discount factor chosen for discounting at time t. As a_t decreases with time, negative values in the early years are weighted more than the positive ones occurring in the later years of a project's life. Therefore, the discount rate and the time horizon are critical parameters for determining the NPV of any project. The decision criterial for NPV is that a positive NPV (i.e. the project generates a net benefit) is preferred. The NPV of a project must therefore be higher than the NPV of mutually exclusive project alternatives (Chowdhury and Kirkpatrick, 1994).

2.7.3.2 Internal rate of return (IRR)

The IRR of a project is the discount rate that makes the net present value of all cash flows equal to zero. The higher the IRR the more desirable it is to undertake the project. In this regard IRR is usually used to rank several potential projects. The decision rule for the IRR is that one accepts projects that have IRR greater than the interest rate (Baum and Tolbert, 1985). A project can therefore be considered financially not viable when its IRR is less than the interest rate. In ranking projects, the project with the highest IRR would be considered the best and should be undertaken first. The IRR is calculated using equation (2).

$$NPV(S) = \sum \frac{S_t}{(1 + IRR)^t} = 0 \ldots .Equation\ (2)$$

2.7.4 Assumptions and sensitivity analysis

If the underlying assumptions are not soundly based the outcomes of the CBA in terms of NPV and IRR are meaningless. Discussions on financial and economic CBA studies should therefore primarily focus on assumptions. Sensitivity analysis therefore allows the determination of the 'critical' variables or parameters of the model. Such variables are those whose variations, positive or negative, have the greatest impact on a project's financial (ICRA, 2015).

3. CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter presents the materials and methods for this study. The methodology consisted of five main sections (see Figure 3.1). The data obtained from the characterisation of jatropha oil and press cake briquettes, interview with key informant, and literature search were fed into business models to determine financial viability. Financial analyses of models that engage small scale farmers were analysed from the perspective of processors and farmers in order to ascertain the impact on the livelihood of farmers. Linear programming models were developed to optimise the use of jatropha oil and by-products based on data from the models. Detailed description of the various methods, materials and models are presented in sections 3.2 to 3.6.

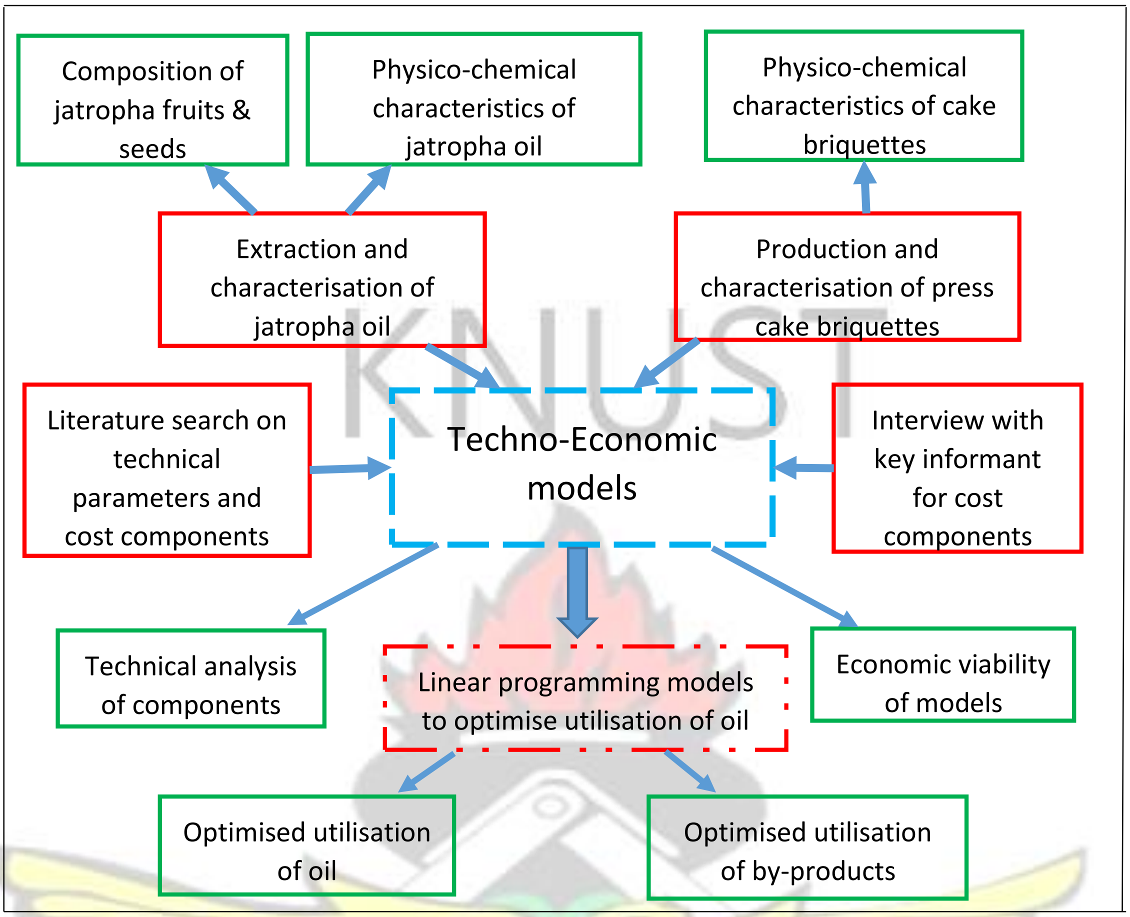


Figure 3.1: Activities, expected outcomes and their impact

3.2 Method for determining composition of jatropha fruit and seed

3.2.1 Raw material preparation

Dried jatropha fruits and seeds were obtained from out grower farmers in *Busunu* in the Northern region of Ghana. The Northern region is characterised by an annual precipitation of 750 to 1050 mm and a temperature range of 14-40°C (MoFA, 2015). Jatropha plantation was 10 years old with annual seed yield of 1000 kg/ha. Seeds were harvested manually and stored in jute bags in a warehouse facility in temperature range of 14-30°C for four months. The experiments were carried out with mechanical screw press (Double elephant screw press Model 6YL-100), powered by a 7.5kW motor with a maximum speed of 40rpm. The maximal capacity of material input is 200kg/h. Other materials used in the experiment included: Digital weighing scale, electronic balance and oven, jute sacks, rubber containers and a stop watch.

3.2.2 Determination of percentage composition of jatropha fruit

5kg of dried jatropha fruits were manually de-hulled and the corresponding seeds and hulls measured with a digital weighing scale. The experiment was repeated five times and the average values obtained. The percentage seeds and hull contents were determined using equations 3 and 4 respectively.

$$\%\ seeds = \frac{weight\ of\ seeds\ (kg)}{weight\ of\ fruits\ (kg)} \times 100 \ldots \ldots Equation\ (3)$$

$$\%\ Hulls = \frac{weight\ of\ \ hulls\ (kg)}{weight\ of\ \ fruits\ (kg)} \times 100 \ldots \ldots Equation\ (4)$$

3.2.3 Determination of percentage composition of jatropha seeds

Moisture content (wet basis) of the jatropha seeds was determined according to the method described by ISI (1966). 10 kg of jatropha seeds were then measured using jute bags and a digital weighing scale. The seeds were pressed and the corresponding oil, pressed cake and residual oil were measured with an electronic balance. The extraction time was measured with a stopwatch. The procedure was repeated five times and the corresponding percentages of oil, pressed cake and residual oil were determined using equation 5, 6 and 7 respectively.

$$\%\ oil\ content = \frac{weight\ of\ extracted\ oil(kg)}{weight\ of\ seeds\ (kg)} \times 100 \ldots \ldots Equation\ (5)$$

$$\%\ press\ cake\ content = \frac{weight\ of\ press\ cake\ (kg)}{weight\ of\ seeds\ (kg)} \times 100 \ldots \ldots Equation\ (6)$$

$$\%\ \ residual\ oil\ content = \frac{weight\ of\ residual\ oil\ (kg)}{weight\ of\ seeds\ (kg)} \times 100 \ldots \ldots Equation\ (7)$$

3.3 Characterisation of jatropha oil

Samples of the crude jatropha oil (100ml) were examined at a biofuel laboratory owned by Oelcheck GmbH in Germany. Table 3.1 shows the various parameters and the standard used for the characterisation.

Table 3.1: Parameters and standards for the characterisation of the oil

Parameter	Standard
Metallic particle and additives (Fe, Cr, Sn, Al, Mo, Sb, Mn, Si, K, Na, Ca, Mg, B, Zn, P, Ba, S)	DIN 51399-1
Acid number	EN 12634
Conradson Carbon Residue	DIN 51551
Density	DIN EN ISO 12185
Flash point	DIN EN ISO 2592
Iodine number	DIN EN 14111
Viscosity at 40 and 100°C	DIN ISO 2909
Water content	-

3.4 Production and characterisation of briquette from jatropha press cake

3.4.1 Raw material preparation and production of briquettes

Two weeks old pressed cake produced during the extraction of jatropha oil at the biofuels laboratory of the Department of Agricultural Engineering, KNUST, Kumasi was used for the briquette production. The jatropha press cake was foremost carbonised using a carboniser and then pulverized with a pestle and mortar. The samples were then sieved with a 3mm Tyler sieve to establish homogeneity. Other materials used in the production process include: starch binder, manually operated screw press, electronic balance and oven, bomb calorimeter, furnace and a crucible. The press-cake briquette was produced according to method described by Pambudi *et al*. (2011).

3.4.3 Characterisation of the briquette

Physical properties such as compressed and relaxed density and shatter index were determined according to methods described by Akowuah *et al*. (2012). Proximate analysis was also performed and components determined included: Percentage volatile matter (PVM), Percentage Ash content (PAC), Moisture content on dry basis (M_{db}), Percentage Fixed carbon (PFC) according to methods described by Akowuah *et al.* (2012). Calorific value was determined according to standard EN14918 as described by kavalek *et al*. (2013).

3.5 Models description

Four business models were developed based on different production models and different scenarios of oil and by-product utilisation. Plantation size of 200 ha was considered as base scenario for the technical and cost benefit analysis of all the models. This is 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. Detailed description of the various models is presented in sections 3.5.1 to 3.5.4.

3.5.1 Description of model 1

Model 1 involves a central company that cultivate large scale standalone jatropha plantation. A study by Schoneveld et al. (2010) which revealed that most biofuel companies in Ghana adopted business models that required large-scale feedstock plantations and export of jatropha oil, was the basis of this model. Crude jatropha oil is extracted from the seeds and subsequently exported. The press cake is then utilised directly as a source of fertilizer on the farm as shown in Figure 3.2.

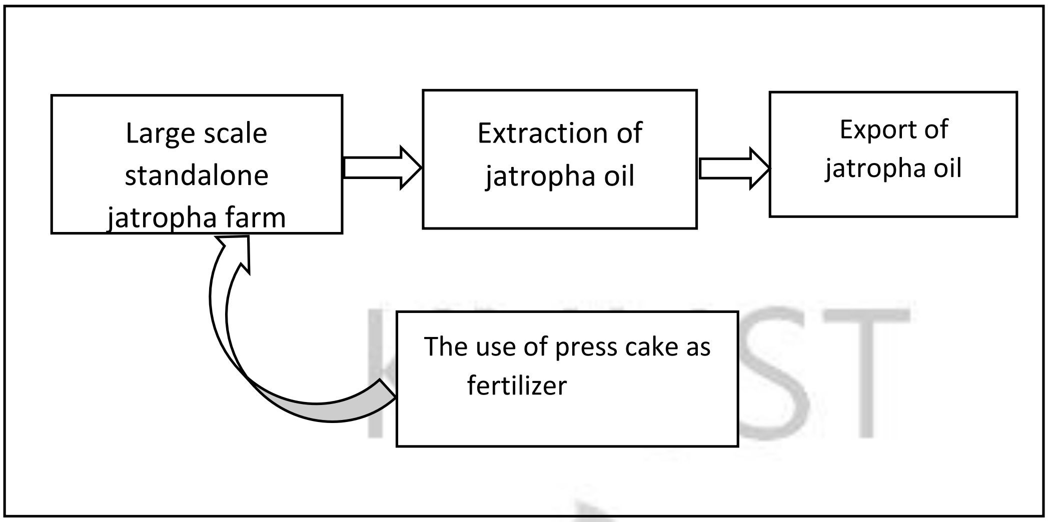


Figure 3.2: Schematic description of model 1

3.5.2 Description of model 2

This model builds on model 1 with substitution of export of oil with local utilisation for electricity and soap production and utilisation of by-product for soap, biogas and briquette production (see Figure 3.3). Six main scenarios were considered under this model (see Table 3.2).

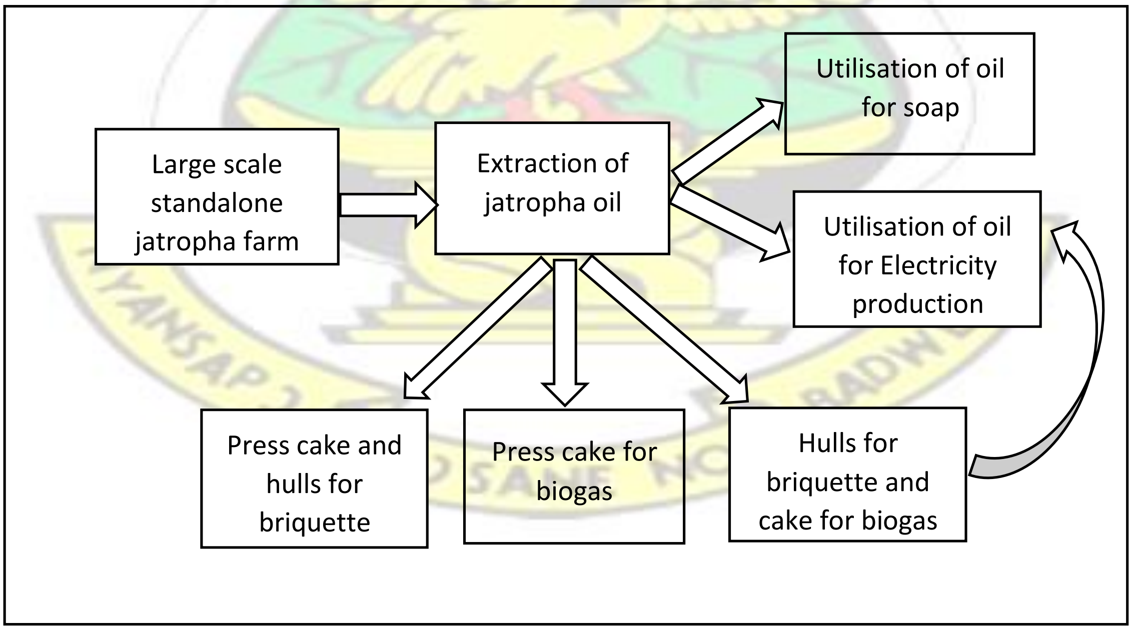


Figure 3.3: Schematic description of model 2

Table 3.2: Descriptions of scenarios under model 2 and 4

Scenario	Description
Scenario 1 (S1a,b)	Utilisation of oil for electricity generation, residual oil for soap and press cake for biogas production.
Scenario 2 (S2a,b)	Utilisation of oil and biogas for electricity generation and residual oil for soap production.
Scenario 3 (S3a,b)	Utilisation of oil for electricity, press cake for biogas, fruit hulls for briquette and residual oil for soap production.
Scenario 4 (S4a,b)	Utilisation of oil for electricity generation, residual oil for soap production, press cake and fruit hulls for briquette production.
Scenario 5 (S5a,b)	Utilisation of filtered and residual oil for soap production, press cake for biogas and fruit hulls for briquette production.
Scenario 6 (S6a,b)	Utilisation of filtered and residual oil for soap production, press cake and hulls for briquette production.

a and b represents scenarios under model 2 and 4 respectively

3.5.3 Description of Model 3

In the third model, small holder farmers and farmer groups are contracted by a central company to produce jatropha seeds by means of intercropping and as hedges. This model uses the buy-back agreement at fixed price method where the promoter signs an agreement with the farmers in which the farmer agree to sell all his/her produce to the promoter. The promoter agrees to buy all the seed at a fixed price per kg. 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 as shown in Figure 3.4

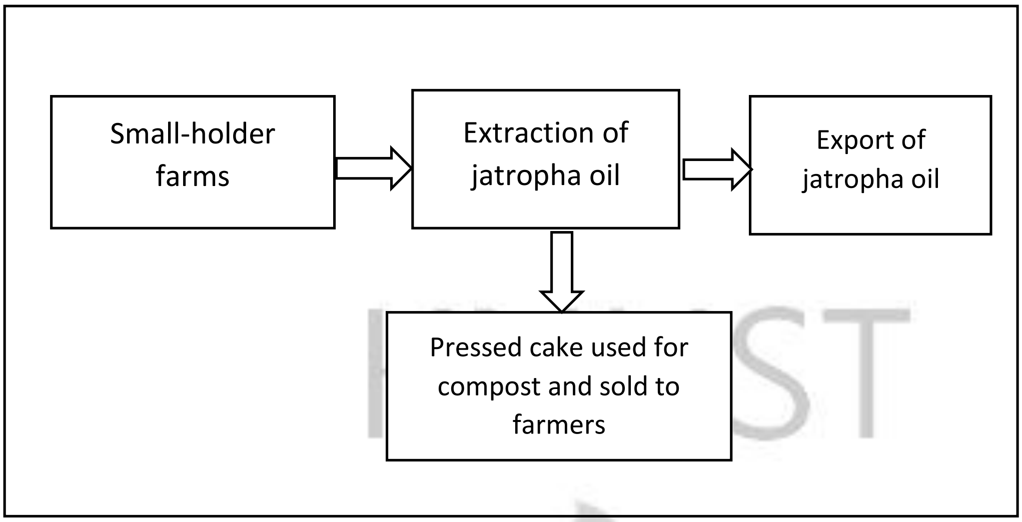


Figure 3.4: Schematic description of model 3

3.5.4 Description of Model 4

This model builds on model 3 with 100% local utilisation of the oil (model 3 had an export component) and by-products as described in model 2 (see Figure 3.5). Six main scenarios (similar to those in Table 3.2) were considered under this model. Table 3.3 presents a summary of the models indicating similarities and differences. Models 2 and 4 differ only by the farming scheme: model 2 is a plantation scheme whereas model 4 is an outgrower scheme. Utilisation of oil and by-products are the same. Models 1 and 3 have the same mode for oil utilisation but differs in the farming scheme and by-product utilisation.

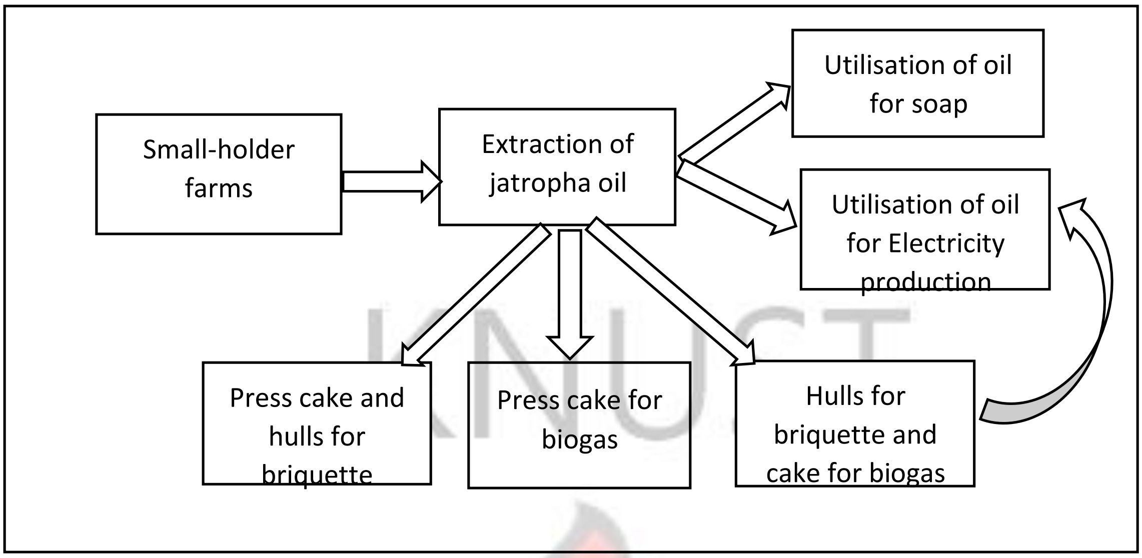


Figure 3.5: Schematic description of model 4

Table 3.3: Summary of the difference and similarities between models

PARAMETERS	MODEL 1	MODEL 2	MODEL 3	MODEL 4
Farming scheme				
Plantation scheme	x	x		
Out grower scheme			x	x
Oil utilisation				
Export	x		x	
Electricity generation		x		x
Soap production		x		x
Utilisation of by-products				
Direct use as fertilizer	x			
Biogas		x		x
Briquettes		x		x
Compost			x	

3.6 Economic and financial Appraisal Methodology

In this section the basic features of cost-benefit analysis are explained in relation to the calculation model of jatropha production and processing. A financial analysis was used to determine the costs and returns from the perspective of the processors and individual farmers in models that utilise out grower scheme. The models and financial analysis and various calculations were carried out using excel computer software.

3.6.1 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. Special emphasis was placed on two financial indicators:

1. Net Present Value (NPV): The NPV was calculated using equation 8

$$NPV = \sum_{t=0}^{n} a_{t} S_{t} = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n} \ldots\ldots\ldots equation\ (8)$$

Where:

$S_t = The\ balance\ of\ cashflow\ at\ time\ (t)$

$a_t = The\ financial\ discount\ factor$

$a_t = \frac{1}{(1+i)^t} \ldots\ldots equation\ (9)$: Where: t is the time between 0 and n (the time horizon) and i is the discount rate.

2. Internal Rate of Return (IRR): The IRR was calculated using equation 10

$$NPV(S) = \sum \frac{S_t}{(1+IRR)^t} = 0 \ldots\ldots equation\ (10)$$

Where symbols have same meaning as in equation 1

3.6.2 Financial Assumptions

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 26th June, 2015 (Ghana Statistical Service, 2015).

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

3.6.3 Estimation of the various cost components of the projects

The method used in the estimation of the various cost components (Investment, working capital and operation and maintenance cost) of the projects consisted of interviews with key informants and extensive literature search (see Appendix 5). The respondents consisted of various stake holders in jatropha, biogas, briquettes, compost and soap production businesses.

3.6.3.1 Estimation of Investment cost

The investment cost considered in this study consists of cost of building, machinery and civil works, cost incurred for jatropha plantation, and other expenses. These components depend on each of the model studied.

3.6.3.2 Estimation of operation and maintenance costs

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 was organized in a table that included:

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.

3.6.4 Revenues expected from the various projects

The revenues expected from the various projects included: crude jatropha oil, electricity, soap, biogas, briquettes, and compost. The unit price of all items was determined using relation shown in Appendix 5. The quantity produced was presented in the various models to determine the revenues generated from each project.

3.6.5 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:

i. Variation in seed yield: 0.55, 4 and 7.5 tonnes/ha ii. Variation in jatropha oil prices: 473, 600 and 1,000 USD per tonne iii. Variation in the purchase price of jatropha seeds: 0.05, 0.07 and 0.16 USD per kg.

iv. 30% increase and decrease in the selling price of briquette, biogas, soap, compost and electricity.

v. Changes in the discount rate: discount rates from 0% to 30% were considered. One of the key variables that determine the NPV of the project is the discount rate. Depending on the decision to take one or other discount rate the project may be financially viable or not viable.

3.6.6 Criteria for assessing the projects viability

As indicated earlier, the economic indicators used to assess the project’s viability were 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 various projects. However, projects with IRR lower than the interest on savings at the bank (25% was used in this case) was considered not financially viable.

3.7 Methodology for optimising jatropha oil and by-products utilisation

Every business establishment seeks to maximize profit with the available resources. This section of the study therefore sought to optimise utilisation of jatropha oil and by-products through profit maximisation. Linear programming models were therefore developed. Linear programming is the most powerful technique that can resolve various issues with regard to the conditions that apply. A linear programming model has an objective function and constraints. An objective function is a mathematical function that consists of a decision variable shown with as Z. It is an indicator of a model's objective. This function represents maximize profit or minimize the cost. Constraints consist of an equation or no equation from decision variables that expresses the limitations of the model or decision in order to research the model objectives shown with (C) (Sidho *et al*., 2004). The linear programming models were solved using mat lab optimisation tool. Table 3.4 presents the objective functions and constraints.

Table 3.4: Objective function and constraints for optimising the utilisation of jatropha oil and by-products

Jatropha oil	**By-products**
Objective function	**Objective function**
$Z_1 = Maximize\ (P) = F_1X_1 + F_2X_2 + F_3X_3$	$Z_2 = Maximize\ (P) = H_1Y_1 + H_2Y_2 + H_3Y_3$
Constraints	**Constraints**
C_1: $X_1 + aX_2 + bX_3 \leq g$	C_1: $eY + sX_2 + jX_3 \leq q$
C_2: $X_1 \leq 0.6g$	C_2: $Y_1 \leq 0.8m$
C_3: $X_2 \leq c$	C_3: $Y_2 \leq 0.6n$
C_4: $X_3 \leq 0.7d$	C_4: $Y_3 \leq 0.7r$
C_5: $X_1, X_2, X_3 \geq 0$	C_5: $Y_1, Y_2, Y_3 \geq 0$

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=Annual maximum profit (USD)
a=Quantity of oil required to produce 1kWh 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)

0.6, 1 and 0.7 are fractions of oil, electricity and soap to be sold annually.

Y_1=Quantity of briquettes required (kg)

Y_1=Quantity of briquettes required (kg)

Y_2=Quantity of biogas required (m^3)

Y_3=Quantity of compost required (kg)

H_1=Unit profit of briquette (USD/kg)

H_2=Unit profit of biogas (USD/m^3)

H_3=Unit profit of compost (USD/kg)

e=Quantity of cake required to produce 1 kg of briquette (kg/kg) s=Quantity of cake required to produce 1m^3 of biogas (kg/m^3) j=Quantity of cake required to produce 1 kg of compost (kg/kg) q=Total quantity of press cake available (kg) m=Quantity of briquettes produced from total cake available (kg) n=Quantity of biogas produced from total cake available (m^3) r=Quantity of compost produced from total available cake (kg)

0.8, 0.6 and 0.7 are fractions of briquettes, biogas and compost to be sold annually.

4. CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

Results and discussions for the study consist of two main parts. The first part consists of the outcomes of the experiment to determine percentage composition of jatropha fruits and seeds as well as characterisation of jatropha oil and briquettes from press cake. The second part presents the techno economic models and optimisation of jatropha oil and by-products utilisation.

4.2 Percentage composition of jatropha fruits

The results from the experiment revealed that, jatropha fruit consists of 34% of hulls and 66% of seeds. Vyas and Singh, (2007) reported that dry jatropha fruit contains about 35-40% hull and 60-65% seed by weight, Abreu (2008) also reported that jatropha fruits contain 37.5% of hulls and 62.5% seeds. The slight variation of the results compared to reported figures in literature can be attributed to differences in variety, environmental and growing conditions, and agronomic practices (Kumar and Sharma, 2008).

4.3 Percentage composition of jatropha seeds

Studies have shown that moisture content of seeds has effect on oil recovery. Bernardin (1982) reported that as moisture content decreases oil recovery increases. The average moisture content of the seeds (wet basis) was determined to be 5.31% which suggest a higher oil recovery. Sirisomboon *et al*. (2009) reported moisture content of 34%. This indicates that the samples used in this study were very dry. From the study an average extraction time and oil content of 9.9 minutes and 30.89% were respectively determined. Oil yield of jatropha seeds varies with environmental conditions (Kumar and Sharma, 2008; King *et al*., 2009), extraction time, moisture content, particle size of the oil-bearing material and temperature (Kabutey *et al*., 2012; Gutierrez *et al*., 2008). The oil content value obtained is in line with reported figures in literature. At a moisture content of 9%, Shkelqim and Joachim (2009) reported oil yield of 31%. Other studies reported figures of 17-18% (Singh *et al*., 2008), 23-39% (Jongschaap *et al*., 2007), 30% (Abreu, 2008) and 30–40% (Pradhan *et al*., 2011). The higher oil content compared to some of the values reported in literature can be attributed to a lower moisture content of the seeds (5.31%). Studies have shown that the use of Soxhlet extraction method generates a high oil yield of 44.41% by weight at 60^{o}C (Asoiro and Akubuo, 2011) and 47.38% (Mani, 2013).

An average percentage press cake content of 65.51% was obtained. This value is within the range of reported figures of 50-75% (Singh *et al*., 2008; Staubmann *et al*., 1997).

Another constituent of jatropha seeds after sedimentation and filtration of the extracted oil is the residual oil. There are no clear values in literature of the percentage of this component of the weight of the seeds. However, it is critical and important to know this parameter as this has been shown to be useful for soap production (Pratt *et al.*, 2002) as considered in the business models presented in this study. Residual oil content of 3.60% of the weight of the seeds was obtained.

4.4 Characterisation of jatropha oil

The use of raw jatropha oil for electricity production was considered in the business models presented in this study. This section of the study therefore assesses compatibility of the use of the raw oil in modified Combustion Ignition (CI) engines. Table 4.1 presents the characterisation results compared to ASTM D6751-02 and DIN 51605 which are recommended values for diesel fuel and vegetable oil respectively. The portion of metallic particles and metal connections can produce blockage within the engine and damage it irreparably. The results showed high level of iron content of 62 mg/kg compared to a reported value of 2.4mg/kg (Carels *et al*., 2009). The strongly raised value of iron can be attributed to the state of the press in which the oil was produced. The press was not state-of-the-art and could have led to a raised metal entry in the oil. The analysis also showed traces of tin, aluminium, copper, molybdenum, antimony and manganese (see Table 4.1). To reduce the metallic particle content to acceptable levels, another chamber filter press must be used and the oil must be stored underground in a plastic container (no solar irradiation, lower temperature, protection against high air humidity) (UFA, 2009). The sample also indicated high levels of additives as shown in Table 4.1. According to DIN 51605 limit values for Calcium, Magnesium, and Phosphorus are 1 mg/kg, 3 mg/kg and 10mg/kg respectively. These values have clearly been exceeded as values of 19, 4, and 47 mg/kg were determined respectively. Sulphur in automobile fuel can cause combustion chamber deposits, exhaust system corrosion. Sulphur content of 0.0015% is recommended for biodiesel (ASTM D5453), which is far lower than the determined value of 0.006% (60mg/kg) for Jatropha oil. Higher moisture content can produce corrosion and cavitation inside the engine, therefore the use of fuel with a portion of emulsified water is not allowed in engines. The samples had a raised moisture content of 0.088% which exceeded the recommended water content for vegetable oil of 0.075% (DIN: 5165). To be able to use the fuel, the water portion must be considerably reduced through treatment by water separator before storage.

Iodine value is a measure of the average amount of unsaturated fats and oils and is expressed in terms of the number of centigrams of iodine absorbed per gram of sample (Knothe, 2002). The oil showed low iodine value (93) due to low content of unsaturated fatty acids (Joshi *et al*., 2011). Iodine values of 105.20 and 135.85 have been reported in Nigeria and Malaysia respectively (Jumat and Rozaini, 2008) and 104.7 in India by Joshi *et al*. (2011). The iodine value serves as a quality control method for hydrogenation. It is used in standards for biodiesel and in assessing oxidative stability. The flash point of a volatile material is the lowest temperature at which it can vaporize to form an ignitable mixture in air. It was determined to be

213^{o}C which is lower than the reported figures in literature; 229.3^{o}C reported by Shambhu *et al*. (2013), 240 ^{o}C by Foidl *et al.* (1996) and 110-240^{o}C by Kratzeisen and Müller (2009). The flash point of fuel has no relation to its performance in an engine nor to its auto ignition qualities. It however provides a useful check on suspected contaminants hence a higher flash point is desired to signify low levels of contaminants. The determined lower flash point may therefore be as a result of high level of contaminants as indicated earlier.

The density of the sample was determined to be 918 kg/m^3 which is higher than the maximum recommended density for diesel fuel as per ASTM D6751-02 (900kg/m^3), The determined value is however lower than the maximum density per DIN 5165 which is 925 kg/m^3 for vegetable oil. Kratzeisen and Müller (2009) reported density of jatropha oil to be 910-920kg/m^3 which is in line with the determined value. To use the oil directly in Perkins Motor 404D-22G engines a maximum oil density of 855 kg/m^3 is recommended. The recommended value can be reached through reduction of moisture as well as an improved filtering. The sample was also analysed for Conradson carbon residue, a property that serves as a measure of the tendency to form deposits on injectors and in the combustion chamber. Carbon residue of <0.01% Wt was determined which is far lower than the reported value of 6.35% by Shambhu *et al*. (2013). The recommended maximum carbon residue for diesel is 0.17% (ASTM D6751-02) which indicates that, the use of this oil may not pose a problem of carbon deposition inside the combustion chamber of engines.

Table 4.1: Comparison of fuel properties of the jatropha oil, diesel fuel and vegetable oil.

PARAMETER	UNIT	Jatropha oil	ASTM D6751-02*	DIN 51605**
Wear				
Iron (Fe)	mg/kg	62	-	-
Chrome (Cr)	mg/kg	0	-	-
Tin (Sn)	mg/kg	2	-	-
Aluminium (Al)	Mg/kg	0	-	-
Molybdenum (Mo)	mg/kg	1	-	-
Antimony (Sb)	mg/kg	1	-	-
Manganese (Mn)	mg/kg	1	-	-
PQ index	-	<25		

Contamination				
silicon (Si)	mg/kg	0	-	-
Potassium (K)	mg/kg	75	-	-
Sodium (Na)	mg/kg	0	-	-
Water content	%	0.088	<0.03	0.075
Oil condition				
Viscosity at 40 ^oC	mm^2/s	37.64	1.9-6.0	36
Viscosity at 100 ^oC	mm^2/s	7.95	-	-
Viscosity index	-	190	-	-
colour	Colour index	8.0	-	-
Additives				
Calcium (Ca)	mg/kg	19	-	1
Magnesium (Mg)	mg/kg	4	-	1
Boron (B)	mg/kg	3	-	-
Zinc (Zn)	mg/kg	26	-	-
Phosphorus (P)	mg/kg	47	-	3
Barium (Ba)	mg/kg	0	-	
Sulphur (S)	mg/kg	60	-	10
Additional test				
Acid number	mgKOH/g	29.75	<0.8	2
Solid contaminants	Mg/Kg	636.7	-	-
Iodine number (J)	-	93	-	125
Density (15^oC)	Kg/m^3	918	875-900	925
Carbon residue	% Wt	<0.01	0.17	-
Flash point	^oC	213	>130	-

***Diesel fuel. ASTM-** American Society for Testing and Materials

****Vegetable oil. DIN**-Deutsches Institut fur Normung (German Institute for Standardization)

Viscosity is a measure of a liquid's resistance to flow. Fuel with the wrong viscosity (either too high or too low) can cause engine or fuel system damage (UFA, 2009). Viscosity at 40^oC of 37.64 mm^2/s was determined, higher than the reported values of 35.4 and 32.6 mm^2/s by Singh and Padhi (2009) and Shambhu *et al*. (2013) respectively and also higher than the recommended value of 36 mm^2/s (DIN 5165) for vegetable oil. This high viscosity may be as a result of insufficient treatment of the oil after extraction. The results indicate that jatropha oil has viscosity 6.3 times that of diesel. To utilise raw jatropha oil in Perkins Motor 404D-22G a maximum viscosity at 100^oC of 4.5mm^2/s is required. The viscosity of the sample at this temperature was determined to be 7.95 mm^2/s. The value determined was therefore about twice the recommended level. The higher viscosity value can be improved in two other steps of treatment by sedimentation and filtering of the oil. Diesel fuel acidity if not controlled, can cause poor fuel stability, corrosion of mild steel and deposit formation in some types of fuel injection equipment (UFA, 2009). Total acid value of 29.75 mg KOH/g was observed for the sample as shown in Table 4.1. Shambhu *et al*. (2013) reported acid value of 32.8 mg KOH/g, and 36.461 mg KOH/g by Joshi *et al*. (2011) and 11 mg KOH/g by Singh and Padhi, (2009). The acid value is higher than the recommended value of 2 mg KOH/g for vegetable oil by DIN 5165. The recommended acid value for diesel is <0.8 mg KOH/g (ASTM D6751-02). The consequential oxidation in connection with high portion of metallic particles and metallic connections within the sample is a possible reason for the raised value. High portion of water in the oil benefits the oxidation process within the tests.

4.5 Characterisation of briquette from jatropha press cake

The use of press cake as briquettes was considered in the business models presented in this study. This section of the study sought to determine the suitability of briquettes from press cake for heat production by identifying physical, proximate and heating values of the briquettes and comparing with existing standards.

4.5.1 Physical characteristics of the briquette

The evaluation of the compressed and relaxed densities was aided by the values of the recorded mass, height, and diameter before and after drying. The average relaxed and compressed densities were determined to be 0.95 and 1.28 g/cm^3 respectively. Relaxation ratio (ratio of compressed density to relaxed density) was determined to be 1.35. According to Yang *et al*. (2005) the lower the value of relaxation ratio and the higher the value of relaxed density, the higher is the stability of briquettes. Comparing reported relaxation ratio range of 1.80 to 2.25 for coconut husk briquettes (Olorunnisola, 2007) to the determined value implies that, the cake briquette is very stable and therefore suitable to be used as fuel source with regard to its stability. Shatter index of the briquette which indicates the durability of the briquette which in turn represents the measure of shear and impact forces a briquette could withstand during handling, storage and transportation processes (Adapa *et al*., 2009) was found to be 0.89. The briquette is durable since the value obtained is closer to 1.

4.5.2 Proximate and heating value analyses

The proximate analysis is a standardised analysis procedure (British Standards Institution, 2004) that quantify some key physical characteristics of biomass that affect its combustion characteristics: moisture content, volatile matter, ash and fixed carbon. Table 4.2 presents the results of the proximate and heating value analyses.

Moisture content of 8% was determined, which is within the limits of 15 % recommended by Wilaipon, (2008), and Grover *et al*. (1994) for briquettes from agroresidues. A much lower moisture content of 1.4% has been reported by Pambudi *et al*. (2011). The percentage volatile matter of the briquettes was found to be 85%. Low volatile content results in smouldering and can be described as an incomplete combustion which leads to a significant amount of smoke and release of toxic gases (Loo and Koppejan, 2008). According to Loo and Koppejan (2008), biomass generally has a volatile content of around 70 - 86% of the weight of the dry biomass. Pambudi *et al*. (2011) also reported volatile content of 66.6%. Another key parameter that affects the combustion property of briquettes is the ash content. Ash is the noncombustible component of biomass; the higher the fuel's ash content the lower its calorific value (Loo and Koppejan, 2008). Fuels with low ash content are better suited for thermal utilisation. Ash content of 4.64% was determined (see Table 4.2), similar value of 4.6% has been reported by Pambudi *et al*. (2011). Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning. Percentage fixed carbon of 26% was determined, which does not deviate widely from the reported value of 27.6% by Pambudi *et al*. (2011). Calorific value (heating value) is the amount of heat liberated per unit mass of the briquette; it was found to be 7,115.7 kcal/kg which is within the acceptable range for commercial briquette according to DIN 51731 (>4179.8 kcal/kg). Table 4.2: Proximate and heating value analyses

Parameter	**Units (%)**
Moisture content (dry basis)	8
Volatile matter	85
Ash content	4.64
Fixed carbon	26
Heating value	
Higher heating value(kcal/kg)	7,115.7

4.6 Techno-economic modelling Results

4.6.1 Introduction

This section of the study presents the results and discussions of the techno-economic models. Technical and economic calculation models for four business cases for jatropha production and processing were considered. The purpose of the models were to provide technical and economic analyses for the production and processing of jatropha oil and utilisation of by-products under four business models. The models allow variation of relevant variables simultaneously to model different project scenarios. This section also presents linear programming models that sought to optimise the use of jatropha oil and by-products through profit maximisation.

4.6.2 Technical and cost benefit analysis of model 1

Model 1 was built on large scale standalone plantation with utilisation of press cake as fertilizer on farm and export of jatropha oil. Planting spacing of 2m by 2m results in a total plant population of 500,000. Other assumption and technical parameters considered for the plantation establishment and financial analysis are shown in Table 4.3. Table 4.4 presents technical parameters and assumption considered for the quantification of jatropha oil and its by-products. With 4.5 tonnes/ha/year of fruit yield, annual quantities of 306, 183, 387 and 22 tonnes of fruit hulls, crude oil, press cake and residual oil were generated respectively. Table 4.4 also presents technical parameters and assumptions considered for the extraction of the oil and parameters for the cost benefit analysis.

Table 4.3: Technical Parameters and Assumptions for Plantation Establishment

Parameter	Value
Plantation size (ha)	200
Planting spacing (m)	2 by 2
Area covered per plant (m^2)	4
Plant population per hectare	2,500
Total plant population	500,000
Lifespan of plantation (years)	30
Production start time (years)	3
Number of seedlings required	525,000
Distance of plantation from processing centre (km)	10
Cost of farm land per hectare (USD)	500
Cost of diesel fuel per litter (USD)	0.99

Cost benefit analysis of model 1 produced investment and annual operational cost of

USD193,533 and USD82,630 respectively (see Figure 4.1). Annual revenue of USD110,092 from the sale of jatropha oil is expected to be generated (see Figure 4.2). At a discount rate of 18% the model generated NPV and IRR of USD -66,472 and 11.87% respectively (see Table 4.5). This indicates that the model is not financially viable since the NPV is negative and IRR is less than 25%. Even with inclusion of revenues generated from carbon credit the model is still not financially viable.

Similar findings have been reported across Africa (van Dorp, 2013; FACT Foundation, 2010a; Romijn et al., 2014).

Table 4.4: Technical parameters and Assumptions for estimation of jatropha oil and by-products and extraction of jatropha oil

Parameter	**Value**
Estimation of quantity of Jatropha oil and by-products	
Fruits per hectare (tonnes)	4.5
Total amount of fruits (tonnes)	900
Total amount of seeds (tonnes) (66% of fruits)	594
Total amount of fruit hulls (tonnes) (34% of fruits)	306
Total amount of crude oil (tonnes) (30.89% of seed)	183
Total amount of press cake (tonnes) (65.1% of seed)	387
Total amount of residual oil (tonnes) (3.60% of seed)	22
Extraction of jatropha oil	
Extraction method	Mechanical
Capacity of screw press (tonnes/hr)	0.1
Total number of crude press required	3
Unit cost of screw press (USD)	5,000.00
Operational hours per year	1,900
Power of motor of screw press (kW)	22
Number of filtering units needed	2
Unit price of filtering unit (USD)	1,200.00
Power of motor of filtering unit (Kw)	1.1
Capacity of de-huller (tonnes/day)	100
Unit price of de-huller (USD)	1,000.00
Power of motor of de-huller (kW)	15
Cost of electricity per kWh (USD)	0.15
Annual electricity consumption (kWh)	148,197
Lifespan of de-huller (years)	20
Lifespan of oil screw press (years)	20

Lifespan of filtering unit (years)	20
Building cost per meter square (USD)	90
Size of building required for extraction, storage & office space (m^2)	250
Selling price of crude jatropha oil per tonne (USD)	600

Contrary to these findings, Alphen (2012) reported that jatropha plantation is financially feasible in Cameroon even with the inclusion of a 20% uncertainty margin. This suggest that financial viability of jatropha plantation may be country specific due to local specifics in cost of labour and other cost components. These results suggest that the failure of most jatropha production and processing companies in Ghana and other Sub-Saharan African countries (Brüntrup *et al.*, 2013) may have been a result of the use of this business model. Critical parameters identified in this model for the sensitivity analysis were discount rate, price of crude oil and seed yield. A study by van Eijck *et al.* (2010) revealed that one problem that appears to be prevalent in cost benefit analysis in literature was either too low or too high estimates of seed yield. This led to overly optimistic or overly pessimistic CBA outcomes. Figure 4.3 presents variation of NPV as discount rate varies from 0 to 30%. It indicates that the model can be financially viable at a discount rate of ≤12%. Increase in seed yield to 7.5 tonnes/ha/year indicated financial viability for the model (see Table 4.6). The study further revealed that for this model to be financially viable, seed yield must be ≥3.6 tonnes/ha/year. Increase in price of crude oil to $1,000/tonne also resulted in economic viability of the model.

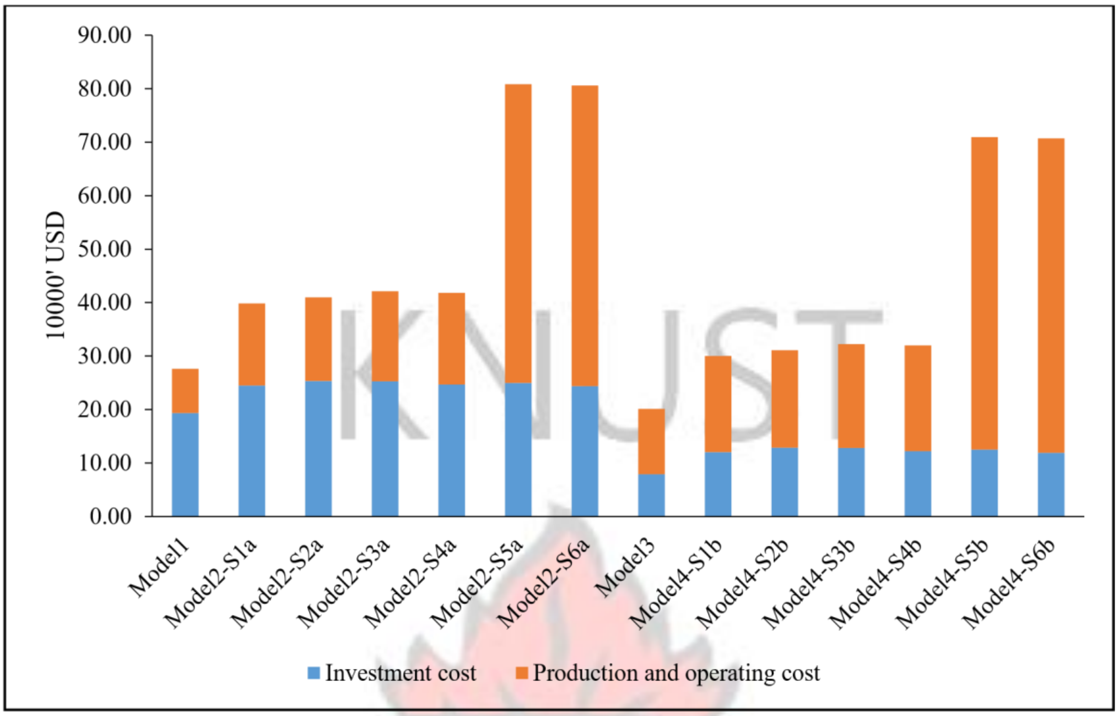


Figure 4.1: Investment and production cost for models and scenarios

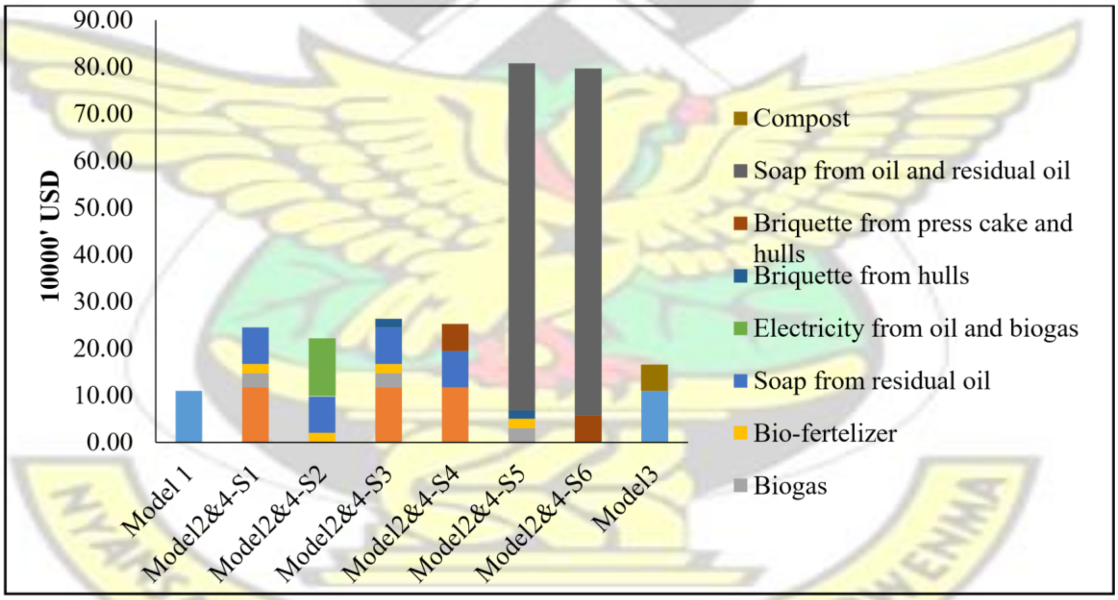


Figure 4.2: Annual revenues generated from the models and scenarios

Table 4.5: IRR and NPV for the base scenario under model 1

	Years			
	25yrs		10yrs	
Parameter	**IRR**	**NPV**	**IRR**	**NPV**
Base Scenario	9.21%	$-93,389	11.87%	$-66,472
Inclusion of carbon credit	11.36%	$-78,803	13.68%	$-47,995

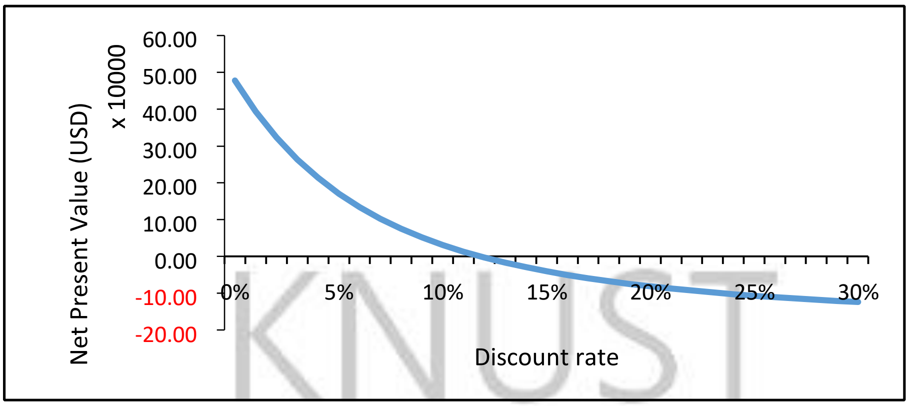


Figure 4.3: NPV curve for model 1

Table 4.6: IRR and NPV for sensitivity analysis under model 1

Years	**10yrs**		**25yrs**	
Parameters	**IRR**	**NPV**	**IRR**	**NPV**
Seed yield				
0.55 t/ha/year	Negative value*	-$328,805	Negative value*	$-368,738
7.5 t/ha/year	47.63%	$349,218	47.78%	$501,820
Price of crude oil				
USD 473/tonne	-11.87%	$-178,366	-3.39%	$-174,118
USD 1,000/tonne	37.47%	$174,254	37.80%	$272,570

* No result given in excel model because values are too extreme.

4.6.3 Technical and cost benefit analysis of model 2

Model 2 was built on large scale standalone plantation with utilisation of jatropha oil and by-products locally. Six main scenarios were considered under this model which utilise the concept of bio refinery with valorisation of jatropha by-products. Table 4.7 presents technical parameters and assumptions considered for biogas production from press cake. It is recommended that for optimal gas production, the size of mesophilic biogas digesters with unaided heating must not exceed 25m^3. Two fixed dome digesters of 25 cubic meter each would be required to anaerobically decompose 386.69 tonnes of press cake annually. With a daily substrate input of 1.77 m^3/day and a retention time of 25 days, annual bio-methane and bio fertilizer of 80,935 m^3 and 106,728 kg respectively are expected to be generated (see Table 4.7). Unit price of bio methane and bio-fertilizer considered for revenue generation were \$0.39/m^3 and \$0.19/kg respectively. Table 4.8 presents technical parameters and assumptions considered for the production of briquette from fruit hulls and press cake. About 411 tonnes of briquette would be generated per annum from 693 tonnes of press cake and fruit hulls. Unit price of briquette was assumed to be \$0.12/kg. The model also considered the production of electricity from crude jatropha oil and biogas. This has been demonstrated for rural electrification in some sub-Saharan African countries (Dimpl and Blunck, 2011). Table 4.9 presents technical parameters and assumption for electricity generation from crude jatropha oil and biogas. Five generators of 16 kW capacity with fuel consumption of 5.4 litres/h would be required to generate 651,095 kWh of electricity from 219,744 litres of oil annually. Biogas generator with capacity of 8kW and fuel consumption of 0.38 m^3/kWh is required to generate 29,218 kWh of electricity annually. Feed in tariff rate of \$0.18/kWh (PURC, 2014) was considered for revenue generation from electricity production. It has been reported that jatropha oil is good and safe for soap production (Pratt et al., 2002; Nielson et al., 2012; Vollner, 2011; Holl et al., 2007). A component of this model was therefore, the utilisation of the filtered and residual oil for soap production. Table 4.10 presents technical parameters and assumptions considered for the soap production and cost benefit analysis. To produce 1 kg of soap, 2.77litres of oil, 2.07 litres of water and 0.41 kg of caustic soda are required. Annual quantity of soap of 88,756 kg is expected to be produced from 245,497 litres of oil and 36,824kg of caustic soda. A unit price of soap bar (180g) of \$1.5 was considered for revenue generation.

Table 4.7: Technical parameters and Assumptions for biogas production

Parameter	Value
Digester type	Fixed dome system
Density of jatropha press cake (kg/m^3)	1,200
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)(350L/kgoTS)	124,515,468.00
Quantity of methane available (L)(65% of biogas)	80,935,054.20
Quantity of methane available assuming 5% losses (L)	76,888,301.49
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

Table 4.8: Technical parameters and assumptions for briquette production

Parameter	Value
Quantity of press cake and hulls available (tonnes)	693
Capacity of briquette machine (t/hr)	0.18
Operational hours	1,750
Number of briquette machine 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)	1,000.00
Power of motor of briquette machine (kW)	15
Capacity of carbonizer machine (t/hr)	0.70
Unit price of Carbonizer machine (USD)	3,000.00
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

Cost benefit analysis of the scenarios under this model revealed investment cost of $244,808.00, $253,053, $252,630, $246,802, $249,682, $243,854 for scenario 1a to 6a respectively. Scenario 1a and 6a had the lowest and highest operation cost of $153,855 and $562,150 respectively (see Figure 4.1). Revenues generated from the various components of the scenarios are shown in Figure 4.2. At a discount rate of 18% all the scenarios had a positive NPV (see Table 12) which indicates that all the scenarios are financially viable. This confirms the assertion by Soto et al. (2013) that valorisation of jatropha by-products might fundamentally increase jatropha profitability.

Table 4.9: 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/hr)	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 8,700 annually	5
Electricity generated (kWh)	651,095
Unit price of generator (USD)	4,269.00
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	3,652.19
Number of generators required	1
Oil consumption (g/kWh)	2
Unit price of generator (USD)	7,000
Lifespan of generator (years)	20
Feed in tariff rate(USD/kWh)	0.18

Size of building for housing biogas generator (m^2)	10

The findings are also in agreement with the assertion of van Eijck *et al*. (2010) that local projects that link seed production closely to local processing and oil use appear to have better potential for achieving financial viability. Scenario 5a had the highest NPV of $901,591. All the scenarios apart from scenario 2a had IRR greater than the interest rate of 25% (see Table 4.11). Scenario 5a and 2a had the highest and lowest IRR values of 62% and 20.76% respectively. Even though IRR of scenario 2a is lower than the interest rate, it is still considered financially viable since the NPV is positive ($43,150) but perhaps not worth the risk.

Table 4.10: 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
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)	2,800
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)	1,895
Unit price of bath bomb press (USD)	275
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 (180g in weight) (USD)	1.5

Critical variables identified for sensitivity analysis of this model were discount rate, seed yield, feed in tariff rate and prices of biogas, bio-fertilizer, briquette and soap. Figure 4.4 presents variation of NPV as discount rate varies from 0 to 30%. It indicates that scenario 2a will not be financially viable at a discount rate >21% and Scenario 1a, 3a and 4a at a discount rate >30%. Decrease in seed yield to 0.55 tonnes/ha/year generated negative NPV's and IRR for all the scenarios (see Table 4.11). This suggest that economic viability of jatropha production even with valorisation of by-products is still highly linked to seed yield.

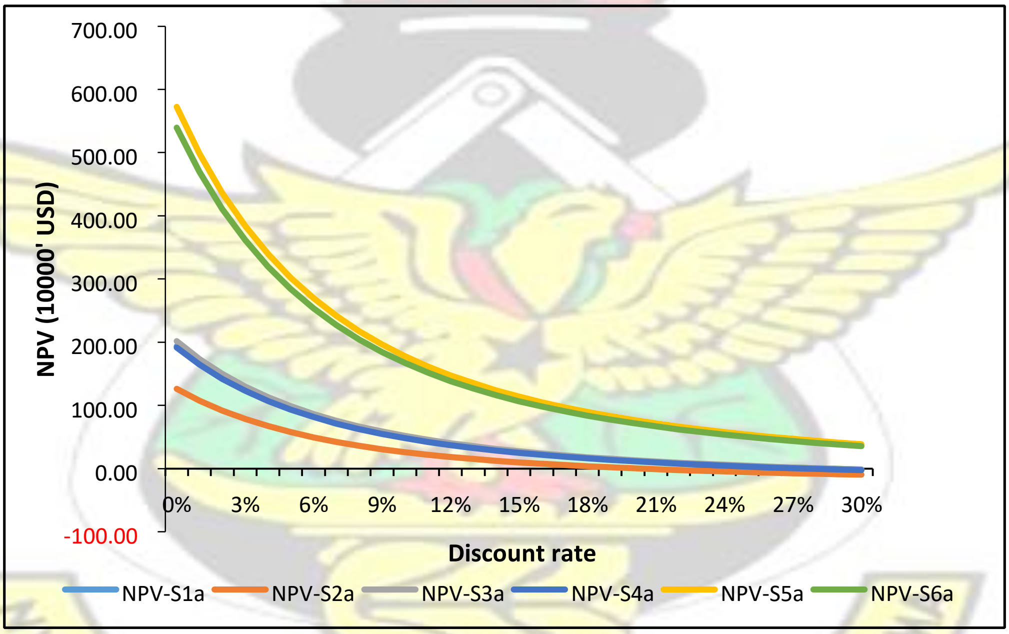


Figure 4.4: NPV curves for the six scenarios under model 2

A thirty percent (30%) decrease and increase in prices of biogas, bio-fertilizer and briquettes produced positive NPV's for the scenarios involved. Increase in the feed in tariff rate to \$0.23/kWh generated a higher NPV and IRR than the base scenario in scenario 2a. This is due to the fact that the bulk of the revenues generated in scenario 2a is from the sale of electricity. Scenarios 2a, 5a and 6a were not financially viable when price of soap was decreased to $1.1/180g since the bulk of the revenues for these scenarios were generated from the sale of soap (see Table 4.2).

4.6.4 Technical and cost benefit analysis of model 3

This model was built on purchase of seeds from contracted small holder farmers and farmer groups that produce jatropha seeds by means of intercropping and as hedges. This model also considered the export of Jatropha oil and utilisation of press cake for compost. Table 4.12 presents technical parameters and assumptions considered for the plantation establishment for the out grower scheme. Based on farm size of 200 ha for the base scenario, 400 farmers are required with the assumption that each farmer cultivates 0.5 ha of land. Planting spacing of 3m by 2m for intercropping situations produced 833 plants for each farmer. A planting distance of 1.5m for hedges implies that, total planting distance of 555.6m is required for each farmer to achieve the required plant population. Purchase price of seeds of $0.07/kg was considered for the base scenario. Farmers who 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 products mentioned (Barbee, 2012). Composting has been shown to reduce the toxicity and oil content of the press cake (Chaturvedi and Kumar, 2012). The production and sale of compost from press cake was therefore considered in this model. Table 4.13 presents assumptions and technical parameters for the compost production. Using a windrow system and a mixing ratio of press cake to bulking agents (grass clippings) of 2:1, 290,021 kg of compost are expected to be generated from 3867 tonnes of press cake annually. A unit price of $0.17/kg was considered for revenue generation from the compost.

Table 4.11: NPV and IRR for the base scenario and sensitivity analysis for the six scenarios under model 2

Parameter	Scenario 1a		Scenario 2a		Scenario 3a		Scenario 4a		Scenario 5a		Scenario 6a	
	IRR 25yrs (%)	**NPV($)**	**IRR 25yrs (%)**	**NPV ($)**	**IRR 25yrs (%)**	**NPV($)**	**IRR 25yrs (%)**	**NPV($)**	**IRR 25yrs (%)**	**NPV($)**	**IRR-25yrs (%)**	**NPV($)**
Base Scenario	29.00	179,129	20.76	43,150	29.17	188,016	28.09	167,537	62	901,591	60.18	842,14
Sensitivity analysis												
Seed yield												
0.55 tonne/ha/year	Negative value*	-417,394	Negative value*	-452,873	Negative value*	-458,626	Negative value*	-447,920	Negative value*	-315,769	Negative value*	-322,760
7.5 tonne/ha/year	64.70	1,300,657	53.24	975,725	66.21	1,403,773	65.85	1,324,662	111	3,190,360	111.8	3,032,260
Price of biogas/m³												
USD 0.27	26.58	137,015	NA	NA	26.83	145,901	NA	NA	60	842,134	NA	NA
USD 0.51	31.39	222,258	NA	NA	31.48	231,144	NA	NA	63	944,720	NA	NA
Price of bio fertilizer/kg												
USD 0.25	30.61	208,006	22.52	72,027	30.73	216,893	NA	NA	63	930,468	NA	NA
Price of briquette/kg												
USD 0.08	NA	NA	NA	NA	27.63	160,027	22.96	78,836	61	873,603	56.55	753,433
USD 0.16	NA	NA	NA	NA	30.68	216,004	32.89	256,237	63	929,579	63.70	$930,834
Feed in tariff rate/kWh												
USD 0.13	19.75	26,261	9.44	-116,579	18.90	35,147	18.96	14,668	NA	NA	NA	NA
USD 0.23	36.91	327,031	29.68	197,688	36.84	335,917	35.93	315,438	NA	NA	NA	NA
Price of soap/180g												
USD 1.1	23.23	81,072	14.22	-55,019	23.60	89,958	22.39	69,479	17	-9,532	13.01	-68,989
USD 1.95	34.70	284,167	26.94	148,076	34.69	293,053	33.74	272,574	96	1,926,605	95.74	1,867,147

* No result given in excel model because values are too extreme. N/A- Not applicable for the scenario

Table 4.12: 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	1,667
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

The cost benefit analysis for this model was done from two perspectives: processor and small holder farmer. Investment and annual operational cost for the processor were \$78,706 and \$122,288 respectively. 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, at 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 4.14).

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 4.5 and 4.6 present variation of NPV as discount rate varies from 0 to 30% for the processor and farmer respectively. It indicates that the project for the processor is financially viable for the range of discount rates considered. However, the farmers can be financially viable if the discount rate is ≤7%. Sensitivity analysis on the selling/purchase price of seeds revealed that at seed price of \$0.05/kg the project is financially viable from the processors' perspective but not viable from the farmers' perspective. The situation is vice versa when the purchase price of seeds was increased to $0.16/kg. (See Table 15).

Table 4.13: 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)	1,734
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)	2,601.
Quantity of compost generated annually(50% volume of input materials) (m^3)	1,301
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)	1,000
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 (^oC)	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 4.14: NPV and IRR for the base scenario and sensitivity analysis under model 3

Parameter	**Model 3-processor**		**Model 3-farmer**	
	IRR 25years	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 4.15: IRR and NPV for Sensitivity analysis under model 3

Parameter	**Model 3-processor**		**Model 3-farmer**	
	IRR 25years	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
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%	$199,888	NA	NA

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

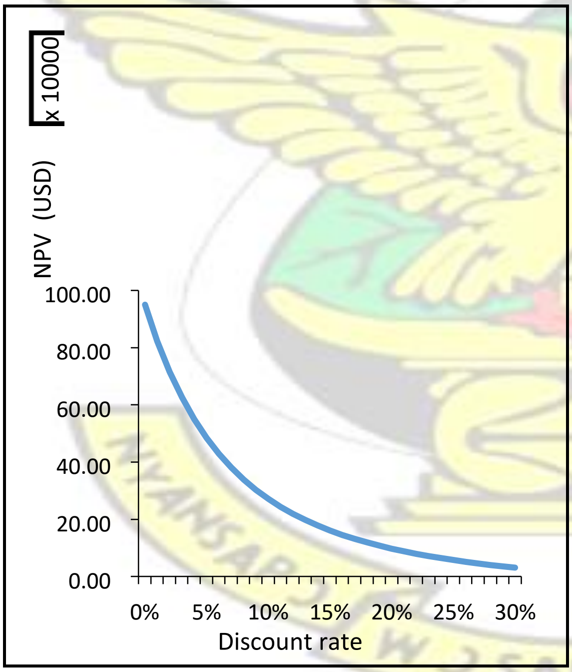


Figure 4.5: NPV curve for model 3: Processors' perspective

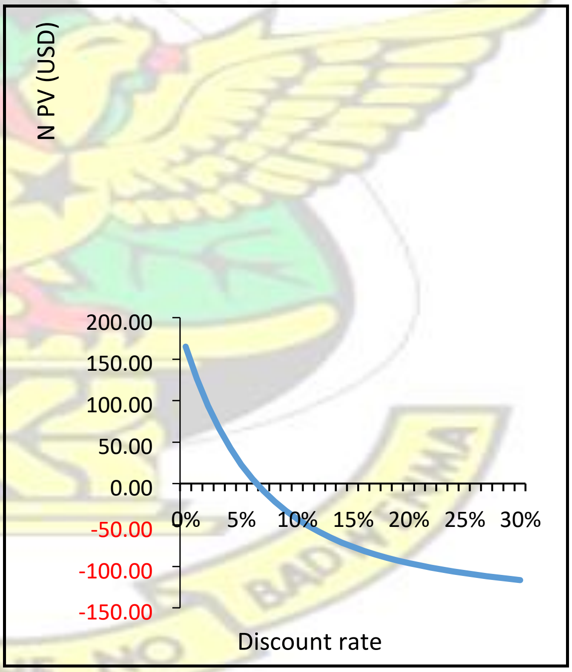


Figure 4.6: NPV curve for model 3: farmers' perspective

Financial viability for both the processor and the farmer was achieved when the purchase price of seeds was $0.1/kg. This generated NPV and IRR of $37,185 and 25.32% respectively for the processor. NPV and IRR of $119 and 29.65% respectively, were realised for the farmer. Even though the project was 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 4.15

4.6.5 Technical and cost benefit analysis of model 4

This model builds on model 3 with the substitution of export of oil with local utilisation of the oil and by-products as described in model 2. This model, like model 2, considered the utilisation of jatropha oil for electricity generation and soap production and utilisation of by-products for biogas and briquettes production. The cost benefit analysis for this model was also done from two perspectives, similar to model 3: processor and small holder farmer. Scenarios 6b and 2b under this model had the lowest and highest investment cost of $119,160 and $128,359 respectively (see Table 4.1). Scenarios 1b and 6b had the lowest and highest annual operational cost of $179,738 and $588,033 respectively. Investment and operational cost from the farmer's perspective were $150 and $90.81 respectively. 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 2b (see Table 4.16). This indicates that all the scenarios under this model are financially viable and confirms the assertion by Soto et al. (2013) that valorisation of jatropha by-products might fundamentally increase jatropha profitability. Scenario 2b had the lowest NPV and IRR values of $48,280 and 23.90% respectively. Even though all the scenarios considered under this model are financially viable from the processors perspective, financial viability from the perspective of the farmer was not achieved since NPV and IRR values of $-88.65 and 7.05% were generated respectively.

Critical variables identified for sensitivity analysis of this model were discount rate, selling/purchase price of seeds, seed yield, feed in tariff rate and prices of biogas, biofertilizer, briquette and soap. Figure 4.7 presents variation of NPV as discount rate varies from 0 to 30%. It indicates that scenario 2b 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 (see Table 4.16). Financial viability can be achieved from the perspective of the farmer if the discount rate is ≤7%.

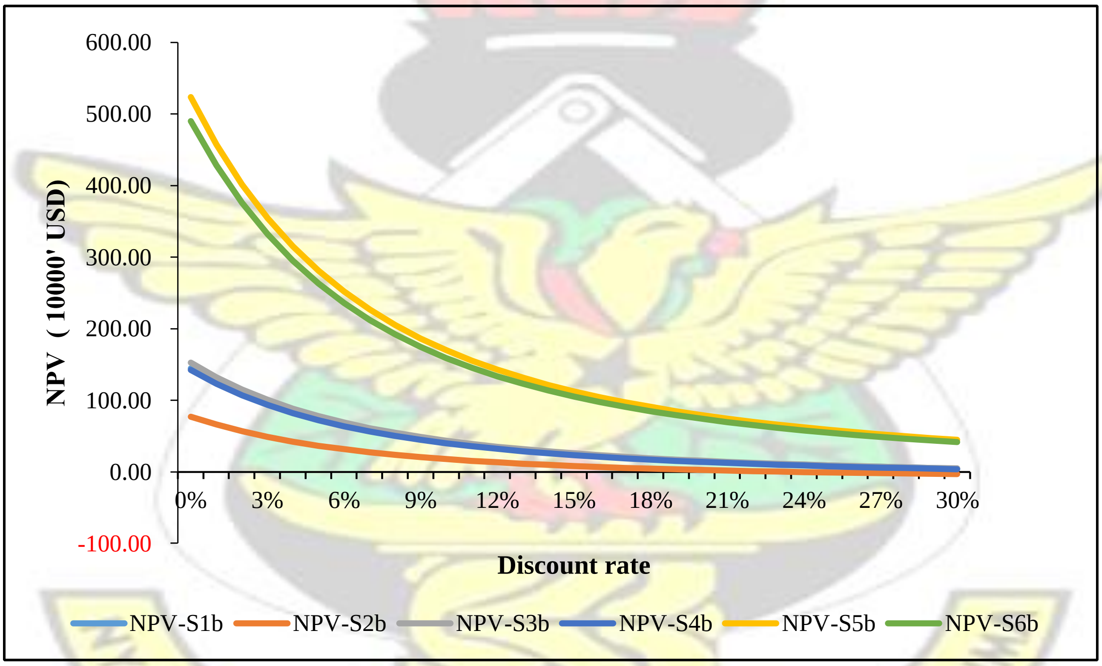


Figure 4.7: NPV curves for the six scenarios under model 4

Sensitivity analysis on the selling/purchase price of seeds revealed that, at seed price of $0.05/kg the projects is financially viable from the processors perspective for all the scenarios but not viable from the farmers' perspective. The situation is vice versa when the purchase price of seeds was increased to $0.16/kg. Apart from scenarios 5b and 6b all the other scenarios were not financially (see Table 4.16). Financial viability for both the processor and the farmer was achieved when the purchase/selling price of seeds was $0.085/kg which generated a positive NPV for all the scenarios and for the farmer. A decrease in the price of soap to $1.1/180g generated a negative NPV and IRR <25% for scenarios 2b, 5b and 6b, since the bulk of the revenues for these scenarios were generated from the sale of soap.

Table 4.16: NPV and IRR for the base scenario and sensitivity analysis for the six scenarios under model 4

Parameter	**Scenario 1b**		**Scenario 2b**		**Scenario 3b**		**Scenario 4b**		**Scenario 5b**		**Scenario 6b**	
	IRR 25yrs (%)	**NPV($)**	**IRR 25yrs (%)**	**NPV ($)**	**IRR 25yrs (%)**	**NPV($)**	**IRR 25yrs (%)**	**NPV($)**	**IRR 25yrs (%)**	**NPV ($)**	**IRR 25yrs (%)**	**NPV($)**
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/180g												
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. N/A- Not applicable for the scenario

Comparing the NPV and IRR for the various scenarios under model 2 and 4 indicated minor differences. Scenarios under model 4 had higher NPVs and IRRs than model 2 (see Table 4.11 and 4.16). This indicate that model 4 (based on out-grower scheme) is preferred over model 2 (based on standalone plantation scheme) provided the purchase price of jatropha seeds is ≤\$0.07/kg. However, increase in the purchase price of seeds to \$0.16/kg resulted in scenarios under model 4 generating lower NPVs than model 2.

4.6.6 Cost Benefit Analysis for utilisation of jatropha oil under the two farming schemes

Models 1 and 2 were built on a common farming model, which is large-scale standalone plantation and models 3 and 4 on out grower farming model. 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 case of oil utilisation is financially viable and profitable under the two farming models. Figure 4.8 shows the investment and production cost for utilisation of the oil under the various models. Generally, the models that utilise plantation scheme had higher investment cost compared to the out grower farming model as a result of higher upfront cost in plantation establishment. The situation is vice versa when it comes to production and operating expenses due to annual purchase of seeds from farmers.

The cost of producing 1 litre of jatropha oil was determined to be \$0.38 and \$0.48 for plantation and out grower schemes respectively (see Figure 4.9) which is lower than the reported figures of \$0.61-1.04 litre (Van Eijck *et al.*, 2012). The difference can be attributed to lower cost of labour and production cost in Ghana. Figure 4.9 also shows unit profit for utilisation of jatropha oil for export, electricity generation and soap production under the various models. Generally, there were higher unit profit in plantation models than out grower schemes for all the scenarios considered. Unit profit of export of oil for plantation and out grower schemes were $0.12 and $0.03/litter respectively. The findings are lower than the reported profit of $0.21/litter (FACT Foundation, 2010a). The use of jatropha oil for soap and electricity production generated the highest and lowest unit profit of $2.28/kg and $0.01/kWh respectively. At a discount rate of 18% NPV values for export, electricity and soap production under plantation scheme were determined to be $-66,472, $-48,340 and $645,854.15 respectively. NPV for export, electricity and soap production under out grower farming scheme were generated 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 farming schemes. This confirms the assertion by Openshaw (2000) that utilisation of jatropha oil for soap making is the most profitable use. The study further revealed that export of oil and electricity production is only profitable at oil price ≥$680/tonne and feed in tariff rate ≥$0.20/kWh.

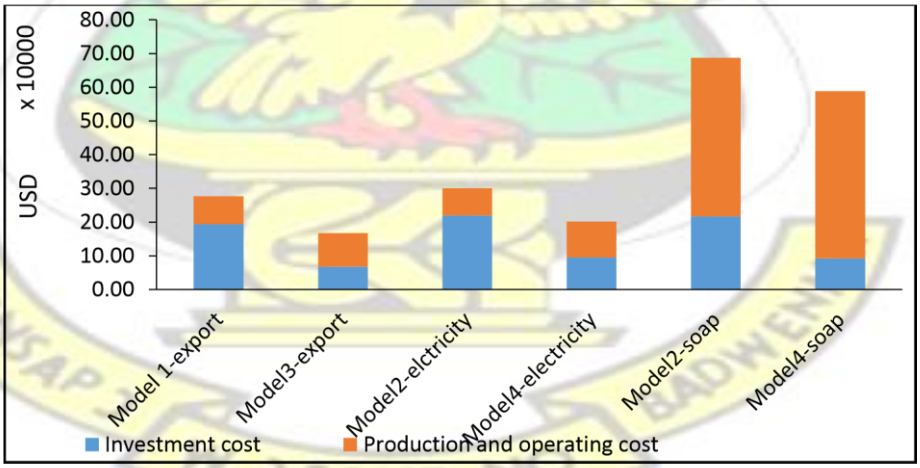


Figure 4.8: Investment and production cost for utilisation of oil under the models

	Model 1oil (litre)	Model3oil (litre)	Model 2electricity (kWh)	Model4electricity(kWh)	Model2soap(kg)	Model4soap(kg)
Unit profit	0.12	0.03	0.04	0.01	2.28	1.96
Unit price	0.50	0.50	0.18	0.18	8.33	8.33
Unit cost	0.38	0.48	0.14	0.17	6.05	6.38

Figure 4.9: Unit price, cost and profit for utilisation of oil under the models

Comparing the NPV's for soap production indicates a higher NPV for the out grower farming scheme than the stand-alone plantation scheme. This suggests that production of soap under out-grower farming scheme is more profitable. Figures 4.10 and 4.11 shows NPV values over the lifetime of the projects under the two farming schemes. It indicates that from the third and second year onwards soap production generates a positive NPV for both farming schemes. Export and electricity generation however had negative NPV's throughout the lifetime of the projects under the two farming schemes.

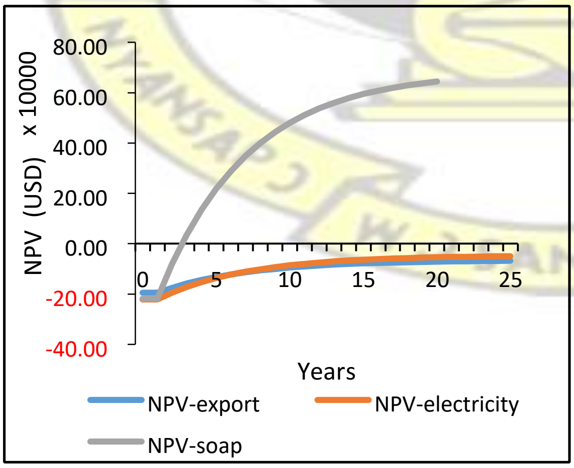


Figure 4.10: NPV over the lifetime of the projects under plantation farming

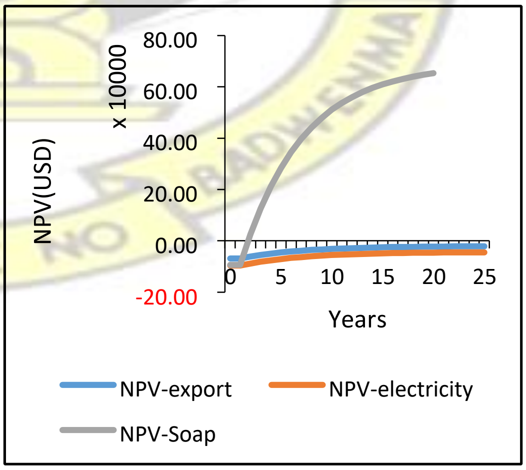


Figure 4.11: NPV over the lifetime of

scheme the projects under out grower farming scheme

Figures 4.12 and 4.13 show variation of NPV as discount rate varies from 0 to 30% for utilisation of oil under the two farming schemes. Soap production was profitable for the range of discount rate considered. From Figure 4.12 it can be seen that export of oil and electricity generation becomes profitable when discount rate are ≤11.87% and ≤14.18% respectively. Figure 4.13 indicates that export of oil and electricity production becomes profitable at discount rate ≤12.91% and ≤9.60%respectively.

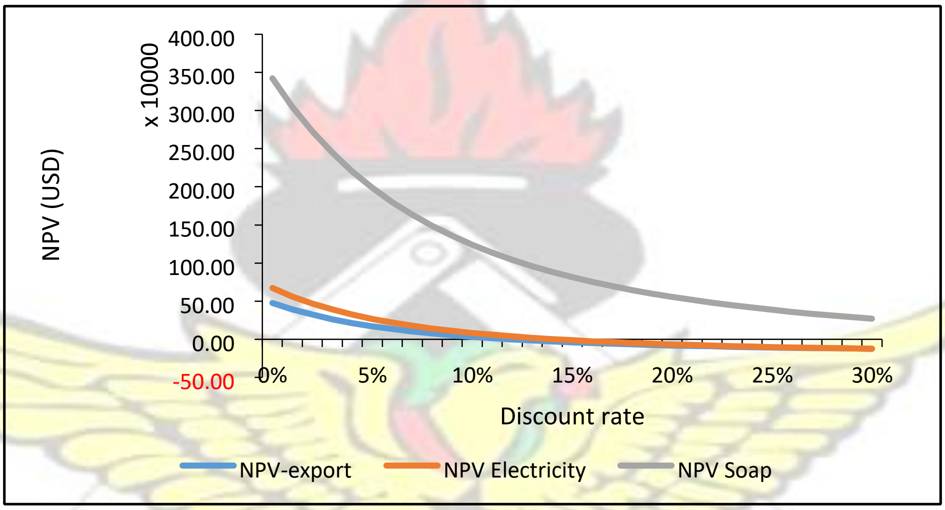


Figure 4.12: NPV curves for utilisation of oil under plantation scheme

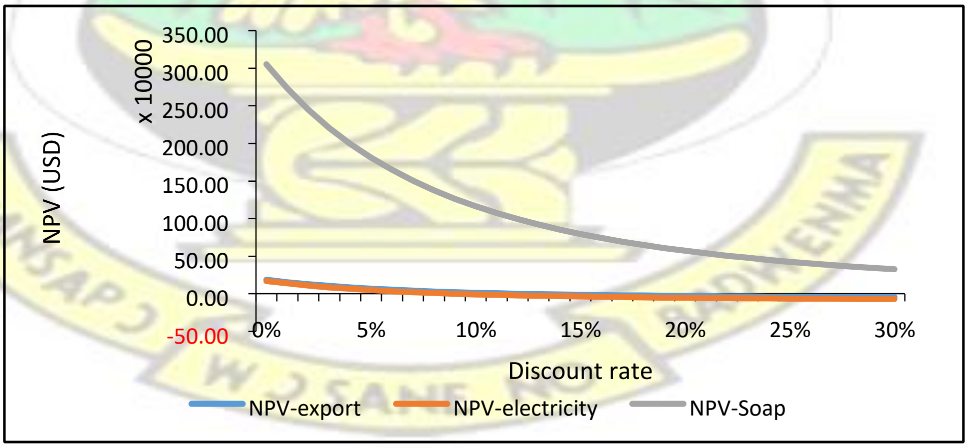


Figure 4.13: NPV curves for utilisation of oil under out grower scheme

Increase in feed in tariff rate to \$0.23/kWh generated NPV of \$102,045 and \$107,176 respectively for the plantation and out grower schemes. Increase in the price of crude oil to $1,000/tonne also generated financial viability. Purchase price of seeds is a very critical parameter in determining the financial viability of utilisation of oil under out grower farming scheme. Figures 4.14, 4.15 and 4.16 show NPV curves for variation of purchase price of seeds for export, soap and electricity production respectively. Export and electricity production show similar variations. They were only financially viable when purchase price of seeds was $0.05/kg. Soap production was financially viable for the range of purchase price of seeds considered.

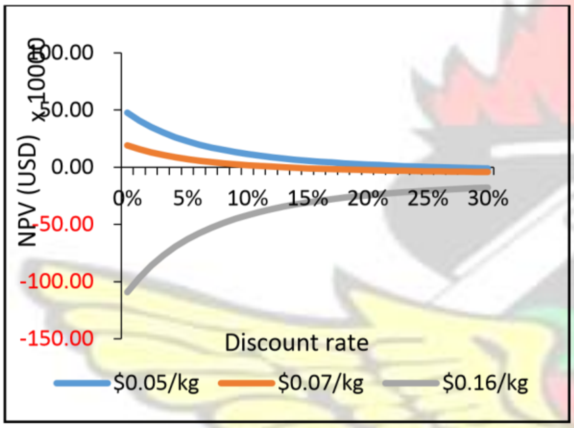


Figure 4.14: NPV curves for variation in purchase price of seeds on export of oil

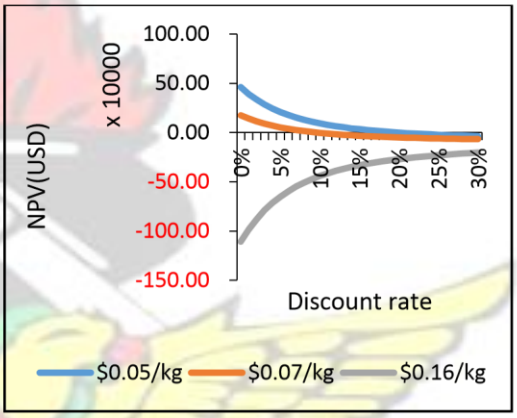


Figure 4.15: NPV curves for variation in purchase price of seeds on electricity production

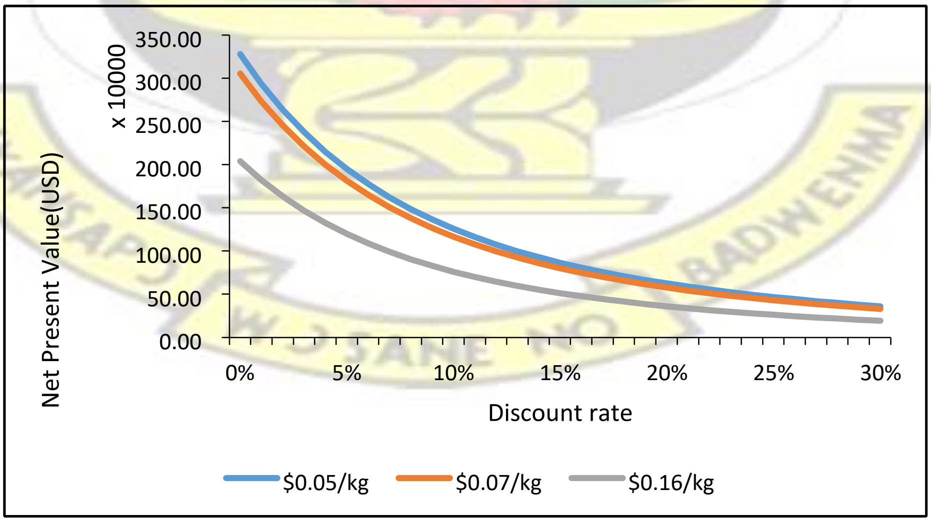
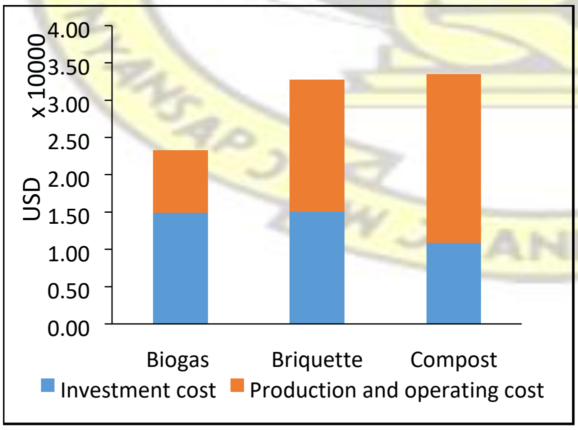


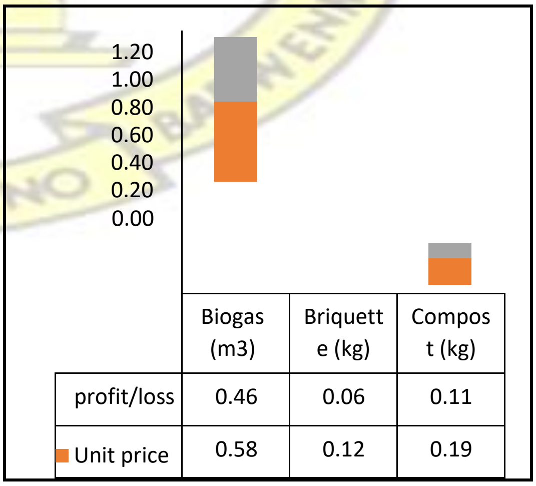
Figure 4.16: NPV curves for variation of purchase price of seeds on soap production

4.6.7 Cost Benefit Analysis for utilisation of jatropha press cake

Three cases for press cake utilisation were considered in the models: compost, biogas and briquette production. This section of the study identifies profitable cases.

Briquette and compost production had the highest and lowest investment cost of \$15,069 and \$10,918 respectively (see Figure 4.17). Compost production had the highest production and operating cost of \$22,572. At a discount rate of 18% NPV for biogas, briquettes and compost were, \$178,724, \$82,268 and \$109,516 respectively and IRR's of 125.03%, 80.21% and 114.27% respectively. This indicates that all the scenarios are financially viable. Biogas production had the highest NPV and IRR as a result of extra revenues generated from bio-fertilizer (slurry). Biogas and briquette production had the highest and lowest unit profit of \$0.46/m^3 and \$0.06/kg respectively (see Figure 4.18). Figure 4.19 shows variation in NPV over the lifetime of the various cases. It shows that by the third year, all the projects attain a positive NPV which indicates financial viability. Variation of discount rate from 0-30% indicates financial viability for the three cases within the range of discount rate considered (see Figure 4.20). Thirty percent (30%) increase and decrease in selling prices of biogas, bio-fertilizer, briquettes and compost showed financial viability for all the cases.





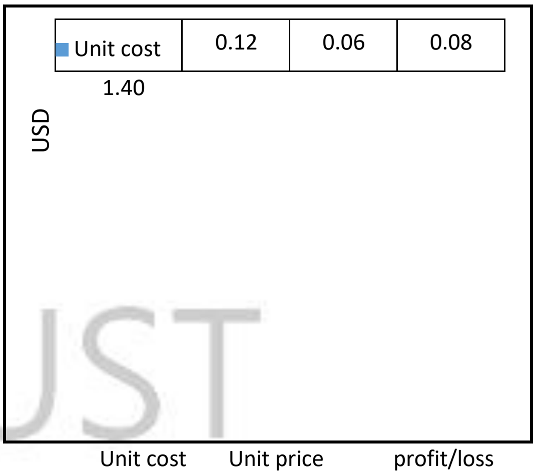


Figure 4.17: Investment and production cost for utilisation of press cake

Figure 4.18: Unit cost, price and profit for utilisation of press cake

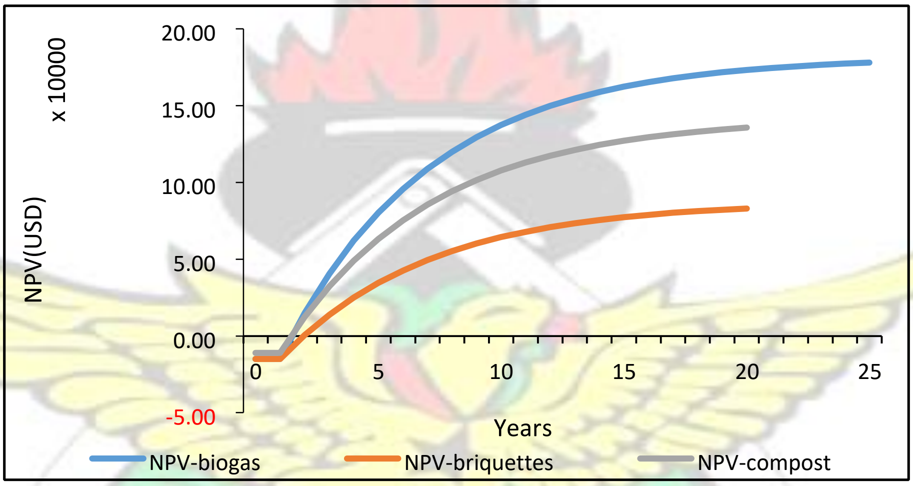


Figure 4.19: NPV over the lifetime of the projects for utilisation of press cake

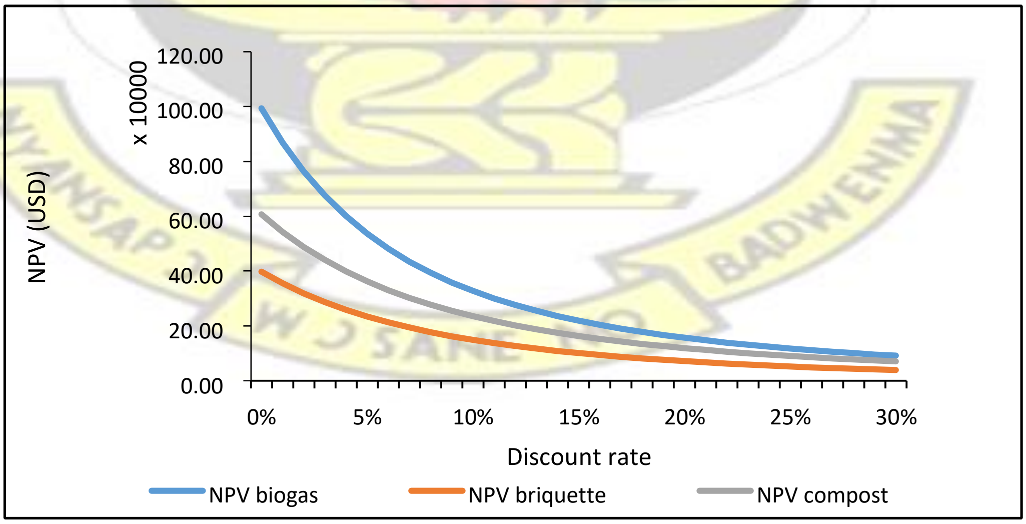


Figure 4.20: NPV over the lifetime of the projects for utilisation of press cake

4.7 Optimisation of jatropha oil and by-products utilisation

Three main cases for oil and by-products utilisation were presented in the 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 materials used in the production of each unit, market availability and unit profit of each product as determined from the models. Table 4.17 presents the objective functions and constraints used in the optimisation of the oil and press cake. For the models that utilise plantation schemes (models 1 and 2), solving the linear equation using simplex method yielded a maximum annual profit of \$147,865. This required the production of 140,135 kWh of electricity and 62,129 kg of soap and export of none of the oil. In the case of the out grower scheme (models 3 and 4), to get annual maximum profit of \$123,300 required the production of the same quantities as presented in the case of the plantation scheme.

Table 4.17: Objective function and constraints for optimisation

Objective function	**Constraints**
Utilisation of oil	
$Z_1 = Maximize\ (P) = 0.12X_1 + 0.04X_2 + 2.28X_3$ *	$C_1: X_1 + 0.34X_2 + 2.77X_3 \leq 219{,}744.43L$
$Z_1 = Maximize\ (P) = 0.03X_1 + 0.01X_2 + 1.96X_3$ **	$C_2: X_1 \leq 131{,}846.66L$
Where:	$C_3: X_2 \leq 651{,}094.61kWh$
$X_2 = Quantity\ of\ electricity\ required\ (kWh)$ $X_3 = Quantity\ of\ soap\ required\ (kg)$ $P = Maximum\ profit\ (USD)$	$C_5: X_1, X_2, X_3 \geq 0$
Utilisation of by-products	
X_1 = Quantity of oil required for export (L)	$C_4: X_3 \leq 62{,}129.45kg$

$Z_2 = Maximize\ (P) = 0.06Y_1 + 0.46Y_2 + 0.11Y_3$ Where:	$C_1: 1.43Y + 4.6X_2 + 2X_3 \leq 386{,}694$ $C\ : Y\ \leq 262\ 853\ 55$
$Y_2 = Quantity\ of\ biogas\ required\ (m\ )$ $Y_3 = Quantity\ of\ compost\ required\ (kg)$	$C_4: Y_3 \leq 203{,}014.35kg$ $C_5: Y_1, Y_2, Y_3 \geq 0$

2 1 , . kg

Y_1 = Quantity of briquettes requires (kg_3) $C_3: Y_2 \leq 46{,}132.98_{m3}$

*Plantation scheme, **Out grower scheme

Performing sensitivity analysis on the linear equation by increasing price of oil to $1,000/tonne yielded a maximum profit of $163,415 in the case of the plantation scheme and $138,726 in the case of out grower scheme. This required exporting 47,646 litres of the oil and producing 62,129 kg of soap. Reducing the price of soap to $1.1/180g generated a maximum profit of $71,180. This required exporting 131,847 litres of oil and producing 258,523kWh of electricity. In the case of out grower schemes decreasing the price of soap to $1.1/180g generated a maximum profit of $7,410 by producing 646,307kWh of electricity. Purchase price of seeds is a very critical parameter in the out grower scheme. Increasing the purchase price to $0.1/kg (recommended price as determined in the models) yielded a maximum profit of $109,129 by producing 62,129kg of soap and zero quantities for both export and electricity.

Optimising utilisation of the by-products for the base scenarios yielded a maximum profit of $22,220. This required the production of 46,133m^3 of biogas and 87,241kg of compost and zero quantities of briquettes. Performing sensitivity analysis on the linear equations by increasing the price of briquettes to 0.16/kg yielded a maximum profit of $27,886 by producing 262,854kg of briquettes and 2,351m^3 of biogas. Decreasing the price of biogas to $0.27/m^3 yielded a maximum profit of $21,324 by producing 19,335kg of compost and zero quantities of briquettes and biogas.

5. CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of this study was to develop techno-economic models for the production of Jatropha oil and optimise its utilisation and that of its jatropha oil and by-products. Jatropha oil and press cake briquette were characterised for physico-chemical properties to determine compatibility for direct use in modified CI engines and heat application respectively. Techno-economic models based on four business cases for jatropha production and processing were further developed. The study further optimised the utilisation of jatropha oil and by-products through profit maximisation.

From the findings, average oil, press cake and residual oil content were determined to be 30.89%, 65.51% and 3.62% respectively. Physico-chemical properties of the oil revealed iron content (62 mg/kg), moisture content (0.088%), iodine value (93), flash point (213^{o}C), density (918 kg/m^3), viscosity (37.64 mm^2/s) and acid value (29.75 mg KOH/g). The findings suggest that using the oil directly in modified CI engine require further treatment using plate filters apart from sedimentation to remove contaminants to recommended levels. Results of the physico-chemical assessment of press cake charcoal briquettes revealed relaxation ratio (1.35), moisture content (8% dry basis), shatter index (0.89), fixed carbon (26%), ash content (4.64%) and calorific value (7,115.7 kcal/kg). The findings suggest that, the cake briquette meets recommended briquette characteristics. Findings from the techno-economic models revealed that model 1 was not financially viable. All the scenarios considered under model 2 were financially viable. Models 3 and 4 were financially viable from the processors' perspective but not for the farmer. Financial viability was achieved for both parties in model 3 and 4 at seed price of \$0.1/kg and \$0.085/kg respectively. The findings indicate that, valorisation of by-products and local utilisation of oil produce financial viability for jatropha production and processing under different farming schemes. The models are however sensitive to seed yield, market prices of crude jatropha oil, soap, biogas, compost, electricity and briquette. Soap and biogas production were identified to be the most profitable use of oil and by-products respectively. The study further revealed that export of oil and electricity production are only profitable at oil price

≥\$680/tonne and feed in tariff rate ≥\$0.20/kWh. Optimising the utilisation of the oil resulted in annual maximum profit of \$147,865. This required the production of 140,135kWh of electricity and 62,129kg of soap. Maximising the utilisation of byproducts resulted in an annual profit of \$22,220 by producing 46,133m^3 of biogas and 87,241kg of compost. The optimisation is, however, sensitive to the prices of crude oil, electricity, soap, biogas, briquette and compost.

5.2 Recommendations

Based on the outcomes of the study, the following recommendations are made.

1. To use raw Jatropha oil in modified CI engines, state of the art oil press must be used with improved filtering of the oil (the use of plate filters) and treatment with water separator before storage.
2. Production and characterisation of soap from filtered and residual oil must be analysed in further studies including its market potential and acceptability.
3. The study considered the utilisation of press cake for briquette, biogas and compost. Pilot studies to determine technical parameters, market potential and acceptability of these products must be assessed in further studies.

4. Models 3 and 4 utilised the out grower farming scheme. The survival of these models are highly dependent on consistent seed supply from small holder farmers, therefore their willingness to go into jatropha production must be assessed.

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7. APPENDICES

Appendix 1: Determination of composition of jatropha fruit

Sample	Weight of seeds (kg)	Weight of hulls (kg)
1	3.8	1.2
2	3.1	1.9
3	3.2	1.8
4	2.9	2.1
5	3.5	1.5
Average	**3.3**	**1.7**
Percentage (%)	**66**	**34**

Appendix 2: Determination of moisture content of jatropha seeds

Sample	Initial weight (g)	Final weight after drying (g)	Weight of water (g)	Moisture content in Wb (%)
1	20.00	19.00	1.00	5.00
2	26.00	24.00	2.00	7.69
3	25.00	24.00	1.00	4.00
4	22.00	21.00	1.00	4.55
Average				**5.31**

Appendix 3: Determination of composition of jatropha seeds

Sample	Weight of oil (kg)	Weight of cake (kg)	Weight of residual oil (kg)	Extraction time (min)
1	2.05	4.75	0.25	12.34
2	2.80	6.05	0.15	13.37
3	3.05	5.45	0.45	8.39
4	2.55	6.05	0.4	8.15
5	2.85	5.9	0.31	7.27
Average	**2.66**	**5.64**	**0.312**	**9.90**
%	**30.89**	**65.51**	**3.60**	-

Appendix 4: Determination of relaxed and compressed density of the briquettes

Parameter	**Compressed briquette**	**Relaxed briquette**
Average initial mass (g)	195	144.25
Average initial volume (cm^3)	151.89	151.90
Density **(**g/cm^3)	1.28	0.95

Appendix 5: References for technical Parameters, assumptions and Cost Components used in the models

PARAMETER	Value	REFFERENCE
Plantation establishment		
Planting spacing	2m by 2m for jatropha plantation and 1.5m within rows for jatropha hedges	Wahl *et al*. (2012) and Mawire (2008)
Lifespan of jatropha plantation	30-50 years	Singh *et al.* (2008)
Production start time (economic yield)	3 years	van Dorp (2013)
Plant yield per ha	minimum 0.55, average 3 and maximum 7.5 tonnes per ha	Francis (2005), Openshaw (2000), Heller (1996), Achten (2008), Ghosh *et al*. (2007), Jongschaap (2007), GTZ (2009) and Van Dorb (2013)
Price of tractor	USD 8,390	http://www.tractors.pk/ghana-previous-offers.html?gclid=Cj0KEQjwo7auBRCOtoqn_s-G7aMBEiQAxArNrPBdxAEauFjTro7v2j8g8eis1oEgm5TkLFkOm6C34hEaArcr8P8HAQ
Price of plough and harrower	USD 1,500 and USD 680 respectively	http://www.aliexpress.com/cheap/cheap-farm-harrows.html
Tractor mounted cutter for weeding		http://www.alibaba.com/showroom/tractor-mounted-grasscutter.html
Price and technical parameters of kia truck	USD 10,000	http://www.alibaba.com/product-detail/used-truck_50013717976.html?spm=a2700.7724857.35.1.EOfMw3 Assesed on 9th September 2015
Cost of farm land per ha	USD 500	Field data (2015)
Cost of land clearing per ha	USD 115	Field data (2015)
Fuel cost for ploughing and harrowing per ha	USD 22	Field data (2015)
Cost of construction of nursery sheds	USD 2600	Field data (2015)
Carbon trading per tree	USD 0.008	Jatropha World (2013)

<u>Small-holder farmers (seed production</u>)		
Labour requirement for land preparation, planting weeding and pruning, harvesting and dehulling	-	Van Eijck *et al*. (2012) GTZ (2009)
Labour requirement for harvesting	40 kg of seeds per person per day	van Dorp (2013)
cost for dehulling	10% of harvesting cost	van Dorp (2013)
Cost of labour per day	USD 7.2	Field data (2015)
Purchase price of seeds per kg	Minimum USD 0.05, average USD 0.07 and maximum of USD 0.16	Van Eijck *et al.* (2010)
General information		
Fuel cost per litter	USD 0.99	NPA (2015)
Electricity cost per kWh	USD 0.15	PURC (2014)
Cost of building per square meter	USD 90	GSS (2011)
Wages of workers	Calculated from daily minimum wage in Ghana- USD 2	http://www.myjoyonline.com/business/2015/January20th/minimum-wage-increased-by-ghc1.php Accessed on 12th August, 2015
Oil extraction		
Percentage composition of jatropha seeds, hulls, oil, press cake and residual oil	66%, 34%, 30.89%, 65.1% and 3.60% respectively	Experimental data (2015)
Price and technical parameters of jatropha de-huller	-	http://www.alibaba.com/product-detail/Dehuller_552004548.html Accessed on 15th August, 2015
Price and technical parameters of oil screw press	-	http://www.jatropha.pro/jatropha_oil_expellers.htm Accessed on 25th August, 2015
Price and technical parameters of filtering unit	-	

Selling price of crude jatropha oil per tonne	Minimum 473 average 600 Maximum 1000	Wahl *et al*. (2012), Jatropha world (2013)
Biogas production		
Density of jatropha press cake	1200kg/m^3	Lestari *et al*. (2008)
Sizing of biogas digester		Ananthakrishnan *et al*. (2013)
Unit cost of digester per cubic meter	300	Field data
Quantity of gas generate from press cake	press cake consist of 92% oTS and biogas generated is 350 L/KgoTS with 65% methane	Stelyus *et al*. (2012)
Quantity of digestate generate	30% of feedstock	Staubmann *et al.* (1997)
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 USD0.39 per m^3	Ananthakrishnan et al. (2013), NPA(2015)
Price of bio-fertilizer kg	Price of bio-fertilizer is assumed to be 1/3 price of chemical fertilizer which is 100 cedis per 50kg bag	Field data (2015)
Briquette production		
Price and technical parameters of briquette machine		http://www.alibaba.com/product-detail/barbecue-charcoalmachine-biomass-charcoal-briquette_1342594014.html?spm=a2700.7724857.35.1.I3lhLC
Price and technical parameters of carbonizing machine		http://www.alibaba.com/product-detail/High-qualityfactory-manufacture-biomass-briquette_1896817002.html

Fraction of cake that remains after compression	0.6	Fact Foundation, (2010b)
Unit price per kg of briquette	USD 0.12 (calculated from average price of wood charcoal in Ghana)	Energy Commission (2014)
Electricity generation		
Price and technical parameters of jatropha oil generator		http://www.alibaba.com/product-detail/20KVASoundproof-Diesel-Generator-Powered-by_60265698698.html?spm=a2700.7724857.35.1.iF073v
Price and technical parameters of biogas generator		http://www.alibaba.com/product-detail/CE-ISO-10KVA-1250KVA-biogas-generator_60088055040.html?spm=a2700.7724857.35.1.4nDNvS
Feed in tariff rate	USD 0.18	PURC (2014)
Soap production		
Quantity of oil, caustic soda and water required to produce 1 kg of soap	2.77 litres, 0.41 kg and 2.07 litters respectively	Henning (2004) and Mawire (2008)
Price and technical parameters of soap mixing tanks		http://www.soapmelters.com/Pot-Tipper-Complete-SoapEquipment-With-Heat-Mix-p/pot%20tipper%20c.htm
Price of caustic soda per 25kg	USD 300	http://www.alibaba.com/product-detail/Caustic-Soda_1948037717.html?spm=a2700.7724857.35.1.pedyJi&s=p
Price of manual cutting moulds (32 kg capacity)	USD 375	http://soapequipment.com/lpmolds/#Manual_Cutter_Soap_Mold_-_Model_MCM2C
Price of soap manual cutter	USD 1,895	http://soapequipment.com/mcutter/

Conditions for optimal compost production: temperature, moisture content, C:N ratio, PH and oxygen concentration	48-65ºC, 50-60%, 25-35:1, 6.5-8 and 10% respectively	van de Kamp *et al.* (1992), Chen *et al.* (2011)
Price and technical parameters of compost screen sieves	USD 1,000	http://www.alibaba.com/product-detail/Greatly-welcomedCompost-trommel-screen-sieve_1749472131.html?spm=a2700.7724857.35.14.p712eV
Price of monitoring devices (compost thermometer, ph meters and moisture meter)	USD 125	http://www.alibaba.com/product-detail/Stainless-Steel-Compost-Thermometer_675547220.html?spm=a2700.7724838.35.1.935CLd&s=p
Price of bath bomb press and moulds	USD 275 and 285 respectively	http://soapequipment.com/bathbomb/
Unit price of drying trays (12 kg capacity)	USD 25	http://soapequipment.com/trays/
Period for curing	two weeks	Mawire (2008)
Unit price of soap per 180g	1.5 USD	Field data (2015)
Compost production		
Percentage volume of input materials that remains after composting	50%	van de Kamp *et al.* (1992)
Ratio of press cake to bulking agent	2:1	Sarpong (2014)

Exchange rate of ₵3.5 to 1 USD was used