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Abstract:

The purpose of the case study is to assess the financial viability of biodiesel production from Jatropha under real-life conditions, in contrast to the more generalised studies currently available. This assessment is modelled from the data of a Jatropha oil producer with a social entrepreneurial business model currently operating in Tanzania and looking to expand into biodiesel production from Jatropha oil. Results from a quantitative cost analysis show that the total cost of biodiesel production is significantly higher than Tanzanian and typical East-African market prices for diesel when including all company costs and taxes; however, when the by-products of the total production process are utilised as additional sources of revenue, biodiesel production becomes financially viable. While these findings are worlds removed from the recently hyped expectations surrounding jatropha as an energy crop, they also do not lend support to the current discrediting of jatropha bio-energy by many who have lost all belief in the crop after projects failed to deliver on the overly positive initial expectations. Jatropha biodiesel production in Sub Saharan Africa can be financially viable as well as socially benign, but only under certain operational conditions that require hard work and considerable time and patience to create.

Keywords:

Jatropha, biodiesel, by-product, financial viability, East Africa.

Highlights:

- Real-world data was used to assess financial viability of Jatropha biodiesel.

- The total cost of biodiesel production was higher than market diesel prices.
- Revenue from by-product utilisation allows biodiesel to be price competitive.
- Biodiesel is projected to be viable under certain conditions, when by-products are utilised.

1. Introduction

Increasing carbon dioxide (CO_2) emissions, climate change, the finite nature of fossil fuels and the subsequent threat of fuel shortages and price volatility, has led to increasing interest in the use of biofuels, such as biodiesel, as substitutes for traditional non-renewable fuels. Such interest in biodiesel is by no means a contemporary development, with the replacement of fossil-based diesel by straight vegetable oil (SVO) dating back to 1900, and the conversion of SVO to diesel (i.e. biodiesel), typically from food crops, tracing its roots to fuel shortages amidst World War II (Songstad et al., 2011). However, in more contemporary times, ongoing worldwide food shortages have raised practical concerns, in addition to both moral and ethical concerns, as to sustainability of the ongoing usage of food crops, producing what is known as first-generation biofuels, to meet the increasing global demands for biofuels (Pimentel and Patzek, 2005). These concerns have led to the development of biofuel production from alternative crops - such as seeds from Palms, Sunflowers, Camelina and Jatropha - aiming to minimise the impact of biofuel production on global food supplies and biodiversity (Eisentraut, 2010).

Jatropha, also known as *Jatropha curcas Linnaeus*, was initially seen as a “wonder crop” for the biofuels industry, both for SVO and biodiesel production, with the promise of a crop that would not compete with food crops, providing competitive seed yields on marginal- and waste-land, whilst requiring little irrigation or management (Brittaine and Lutaladio, 2010; Robinson and Beckerlegge, 2008). The reaction to such claims was the planting of over 900 000 ha of Jatropha by 2008, with projections of up to 12.8 million ha to have been planted by 2015 (Kant and Wu, 2011). However, a growing number of studies such as those of Burley and Griffiths (2009) and the German Technical Cooperation (GTZ) (2009) urge caution over such positive claims, arguing that the claimed Jatropha crop performance is vitally dependent on resource- and labour-intensive processes, a big step from the initial claims of wasteland based viability. More stringent detractors, notably Kant & Wu (2011), take this critique of Jatropha as a biofuel crop a step further, arguing that Jatropha as a biofuel-crop is a failure, citing comparatively poor performance to alternative fuel crops such as sunflower, in addition to highly variable seed and oil yields and poor financial returns as evidence that Jatropha should be abandoned in favour of alternatives for future biofuel production.

Unfortunately, these conflicting sentiments towards Jatropha provide a seemingly "black or white" perspective of the potential (or lack thereof) of Jatropha, painting overly positive or negative pictures of its place as a feedstock in the biofuel industry, with little room for a more detached analysis. However, the concerns raised by such polarity of opinions in the Jatropha debate are not recent, with Achten et al. (2008) stressing the need for further conservative, scientifically based studies into the viability of Jatropha as a biofuel, due to the relative absence of such in available literature. In spite of these concerns, the situation has not changed greatly up to 2013, with Shumba et al. (2013a) calling for studies to fill the void of factual information on Jatropha as a potential biodiesel feedstock.

The purpose of this paper is to help "clear the air" with respect to this polarity of opinions surrounding Jatropha in recent years, and provide some sorely needed factual information regarding the financial side of biodiesel production from Jatropha. More specifically, this paper shows that under real-world conditions, Jatropha still has scope to be utilised as an effective and financially viable method of biofuel (biodiesel) production, in spite of estimates that the cost of Jatropha biofuel production can be up to 2.5 times that of equivalent fossil-fuel production (Sale and Dewes, 2009). This paper presents the results of a detailed real-world case study, analysing the financial viability of biodiesel production from Jatropha oil via traditional transesterification methods. This analysis is conducted from the perspective of an established Tanzanian Jatropha oil producer seeking to enter into the biodiesel production market.

2. Objective and Scope

The overall objective of the authors is to establish that environmentally and socially sustainable Jatropha-biodiesel production, as sought after by the Tanzanian Jatropha oil production company in this case study, can be financially viable and even profitable. This objective is quantitatively verified in the subsequent sections of this case study, following the method and process for the production of biodiesel from Jatropha outlined in sections 3.1 and 3.2.

In attempting to complete a realistic assessment of the financial viability of biodiesel production from Jatropha, real-world data was used for the following case study, based upon the yearly operations of the aforementioned Tanzanian Jatropha oil production company. However, at the behest of this company, the analysis of their financial prospects with respect to biodiesel production from Jatropha required that they remain as an anonymous source for the provision of all practical data used in this case study.

This case study begins with a description of the biodiesel production process designed for use by the company. The cost of Jatropha biodiesel production is then calculated based on conservative process cost descriptors. Following this, the total cost of biodiesel production is compared with the current market prices for diesel in Tanzania and surrounding East African countries to assess the financial viability of the case study process. Upon completion of the financial viability analysis, the case study concludes with the authors' perception of the viability of Jatropha utilisation as a biofuel crop.

3. Method and Case Description

The method undertaken in this case study will be the financial analysis of the current cost of Jatropha oil production by the company, following which the subsequent cost of the production of biodiesel will be calculated. These calculations will be completed using the operational information provided by the company, with a suitable biodiesel production process having been developed for the company by the authors (see section 3.2) in order to enable the costing of the conversion of Jatropha SVO to biodiesel. Current fuel-market conditions will then be assessed, and the potential profits from the sale of pure Jatropha SVO and Jatropha biodiesel at Tanzanian (and other East African countries) market prices will be examined.

3.1 Case Study Background

The Tanzanian Jatropha oil production company, used as the source for this case study, hereafter described as 'the company', has been producing Jatropha oil in Tanzania for over 8 years, sourcing its Jatropha seeds via a sustainable, socially-orientated smallholder outgrower model. This model attempts to avoid the prohibitive costs of self-managed Jatropha plantations (NL Agency, 2013), whilst providing additional income to farmers, by sourcing its Jatropha seeds from boundary land which has low or zero opportunity costs for the smallholder farmers, and would otherwise remain unused. As of 2012 the company was working with over 50 000 smallholder farmers, with an aim of reaching over 100 000 smallholders over the next 2-3 years. Collection centres run by more than 400 collectors are located near strategic places such as in grocery shops, schools or on the properties of well-known farmers. Farmers bring their seeds to these collection centres, and the company organises onward seed transport to its central processing centre using local transport companies and one self-owned truck. A “backhaul system” is used for this, utilising trucks that would otherwise return empty to town after delivering their products upcountry. Following collection of the seeds, SVO is produced using mechanical pressing and subsequent filtering, using methods similar to those described by Beerens and van Eijck (2010).

In 2012 over 500 tonnes of seeds were collected and processed into SVO, with a target of 1000 tonnes of seeds to be processed in 2014. At present, the company is solely focused on the production and sale of SVO from Jatropha, however, there is interest in moving into biodiesel production, utilising the SVO that is currently being produced. This interest resulted in the completion of an assessment of the financial viability of biodiesel production from Jatropha by the authors, as presented in this case study.

It was found that the vast majority of Jatropha-biodiesel studies were highly technical, with the focus lying with the technical process description, with no assessment of the financial realities of such processes in the real-world. Other studies tended either towards calculation-based evaluations which were overly generalised, leaving out specific costs and factors vital to the final cost of biodiesel production such as in Shinoj et al. (2010), or towards brief reviews such as in the case of Achten et al. (2009) and Kuona et al. (2013), which tend to briefly mention the possibilities inherent with Jatropha as a biofuel feedstock using existing literature, but do not take the necessary step of using these values to then provide a quantitative financial measure of these possibilities. In addressing this gap in the existing literature, a realistic and quantitative assessment of the future potential of Jatropha as a biofuel (such as biodiesel) is striven for within this case study.

3.2 Biodiesel Production Process

As part of the financial assessment of biodiesel production from Jatropha conducted by the authors on behalf of the company, a biodiesel production process suitable for the social and environmental conditions in terms of material availability, costs and biodiesel quality was developed. This process, as described in Figure 1, focuses on the required steps to produce biodiesel after the production of SVO from Jatropha seeds, as the costs pertaining to the production of SVO from Jatropha were provided by the company as outlined in the calculations in section 4 of this paper. Due to the operational conditions of the company both in terms of available capital and available feedstock (i.e. Jatropha seeds), it was decided to develop a process that was as simple as possible whilst retaining a standard of biodiesel output suitable for use in vehicles.

[Insert Figure 1, in colour, here]

For each of the individual steps in this process, specific materials were required to facilitate the conversion of SVO to biodiesel (much like ingredients in a recipe), whilst certain by-products were produced during individual steps.

3.2.1 SVO Production from Jatropha Seeds

Whilst not designed by the authors, the preexisting SVO production from Jatropha seeds is a key step in the biodiesel production process. As such, the required materials, equipment and labour for the extraction of SVO from the collected Jatropha seeds is detailed for later use in determining the cost of SVO production from Jatropha, and subsequently the cost of biodiesel production, and is given in Table 1. More specifically, the SVO production process involves sorting the good, usable seeds from the unusable seeds. These good seeds are then pressed, producing SVO which is subsequently filtered, in addition to producing sludge and seed cake. The sludge and seed cake is then re-pressed to extract a small percentage of extra SVO which is then filtered, whilst the seed cake is then converted into briquettes using a briquetting machine, to be later sold as a firewood replacement fuel source.

[Insert Table 1, here]

3.2.2 Degumming

As the first step in the proposed biodiesel production process from the Jatropha SVO produced by the company, degumming is designed to remove almost all of the gums (phosphatides) and lower the phosphorous content present in the oil which could interfere with subsequent refining steps such as transesterification (Aly, 1992). The degumming process was taken from Humana People to People India (2009) and is described below, with the resulting materials required to produce degummed SVO outlined in Table 2.

[Insert Table 2, here]

The SVO is first heated to a temperature of 60°C. As the temperature is achieved, 0.01% phosphoric acid (H_3PO_4) by weight of Jatropha oil (or 0.000090317g of H_3PO_4

per litre of SVO, using the density of Jatropha of 0.90317 kg/L given by (Akbar et al., 2009)) is added to the SVO and is then stirred for 30 mins. Then, 2% water (20 ml of water per litre of SVO) is added to the oil, which is then heated to 80°C for nearly 15 mins. Gums present in the oil will settle down and can then be drained from the Jatropha oil.

3.2.3 Transesterification and Neutralisation

Following the successful degumming of the SVO, the process of transesterification is undertaken to convert the SVO into biodiesel. This process involves a simple chemical reaction in which the SVO is combined with a catalyst and a pure alcohol to form raw biodiesel, glycerine and soap; this process also results in the neutralisation of any excess free fatty acids (FFAs) in the SVO (FACT Foundation, 2010). Given the need for the final biodiesel product to be of a high-quality, the transesterification process given by the FACT Foundation (2010) was combined with the process proposed by the Make-Biodiesel organisation (2013a) – designed to produce biodiesel meeting the standards of the American Society for Testing and Materials (ASTM) – to give the following SVO transesterification process to produce biodiesel, with the resulting materials required to produce raw biodiesel outlined in Table 3.

[Insert Table 3, here]

The catalyst, lye (potassium hydroxide, KOH), is dissolved in pure methanol. The required quantity of KOH is (8 + 1.15 * titration number) grams per litre of SVO, where the titration number of the SVO is found using the titration process given by the Make-Biodiesel organisation (2013b), whilst the required quantity of methanol is 0.22 litres per litre of Jatropha oil (i.e. 22% by volume). The mixture is stirred for up to 10 minutes until all of the KOH has dissolved into the methanol, creating potassium methoxide. The SVO is then placed in a large vessel (at least 150% of the volume of the SVO) with a valve at the bottom (to later drain the glycerine and soaps from the biodiesel) and heated to roughly 60°C, following which the methoxide mixture is added and the mixture is stirred for a subsequent 10 minutes. Following the transesterification process, the different constituents are left to separate by sedimentation for 8 to 24 hours, with the glycerine and soap settling out to the bottom; the glycerin and soap can be used as value-added by-products. This sedimentation can then be drawn off via the valve in the bottom of the tank, leaving raw biodiesel.

3.2.4 Washing

In keeping with the need for an overall process suitable for the operational conditions of the company in Tanzania, the final purification process to convert the raw biodiesel into biodiesel ready for use was modelled on a waterless washing process from the FACT Foundation (2010). More specifically, this process utilises Magnesium Silicate (also known as Bleaching Earth) to provoke any impurities remaining in the raw biodiesel to settle, allowing them to be filtered out of the biodiesel, in addition to reducing the colour pigmentation and odour of the biodiesel.

The exact material requirements were based on the process of the organisation Fryertofuel (2013), which suggest the use (at maximum) of 1% by weight of magnesium silicate to raw biodiesel. Based upon this process, roughly 0.88 grams of magnesium silicate is added per litre of raw biodiesel and then mixed for 20-30 minutes (Fryertofuel, 2013). Following the mixing, the biodiesel-magnesium-silicate mixture is allowed to settle for an hour, following which the settled magnesium silicate is removed. The final step requires the filtration of the remaining biodiesel through a 5 micron filter to ensure all traces of magnesium silicate have been removed.

3.2.5 Biodiesel

Upon completion of the above process steps, the SVO is converted completely into high-quality biodiesel. The rate of conversion for SVO to biodiesel has been quoted as high as 98% (Lee et al., 2013; Highina et al., 2011), but for the sake of a conservative approach, the process proposed by the authors (for subsequent financial analysis calculations) is assumed to have an approximate conversion rate of 95%.

4. Theory/Calculation

Following the development of a practical method for the conversion of SVO from Jatropha to biodiesel, as outlined in section 3.1, the authors conducted a complete financial analysis of the cost to the company of producing biodiesel under the operational conditions of the company in Tanzania. This process included all company costs, but also took into account both known values and conservative projections with regards to the potential for by-product production from the SVO production and biodiesel production processes. By including all company costs in the final production price of biodiesel and thus shifting the focus of the company from SVO production and sales to biodiesel production and sales, the authors were interested in determining the level of viability of biodiesel production from Jatropha as a whole, in addition to when by-products were and were not utilised by the company.

4.1 Known Values and Assumptions

In order to complete the financial cost calculations, the operational values and costs pertaining to the company whose data was used in this case study and the general

Tanzanian market price for pertinent SVO to biodiesel process materials was first collated. Table 4 outlines the unit costs which go directly into purchasing and processing the Jatropha seeds into SVO under the current operational conditions of the company. Table 5 details the SVO to biodiesel conversion process, and outlines the material costs for all the required ingredients as outlined in section 3.2.

[Insert Table 4, here]

[Insert Table 5, here]

4.2 Overhead Costs

The total overheads for the Tanzanian based company were taken from the 2012 financial year in order to obtain a value for a complete financial year. These costs included general capital costs (including SVO production line rental costs), building rental costs, electricity consumption, water use, and permanent staff wages for the company bookkeeper, cook, security watchman, production supervisor and the general manager. These overhead costs were quoted to be fairly fixed from year-to-year, and totalled at US$103 000 per year.

4.3 Equipment Costs

The equipment costs born by the company, and not included in the overhead can be separated into two categories: SVO production equipment, and biodiesel production equipment. For SVO production, the majority of the equipment cost is actually covered in the company overhead costs, as at the time of writing, the entire SVO production line was being rented by a neighbouring firm, with only the briquetting machine (used to create the briquette by-products from the seed cake) being owned by the company. In contrast, due to the fact that the company currently has no biodiesel production capabilities, it was assumed that a system would need to be purchased. Furthermore, in keeping with a conservative outlook, and after consultation with the company, it was assumed that the average lifetime of the processing equipment would be taken as 5 years before it would need to be replaced. With these facts and assumptions in place, the cost of equipment for the separate processes of SVO production and biodiesel production were calculated, as detailed in Table 6.

[Insert Table 6, here]

4.4 Cost of SVO Production

Using the required materials for SVO production from section 3.2.1, the unit costs for Jatropha seed collection and processing to SVO given in Table 4, and the company overhead costs given in sections 4.2, the actual current cost of the production of SVO by the Tanzanian based company was calculated, and is outlined in Table 7.

[Insert Table 7, here]

[Note: the equipment costs for the SVO production are included as part of the overhead costs, whilst the briquetting machine costs is assumed to only impact upon the briquette by-product revenue.]

4.5 Cost of Biodiesel Production

The projected cost of the production of biodiesel from Jatropha SVO was based upon the production process outlined in section 3.2, the material unit requirements in Tables 2 and 3, and the unit cost for the required process materials in Table 5, in addition to the current cost of producing SVO which is given in Table 7. Using these values, the cost of the individual biodiesel production steps, and subsequently the total cost of biodiesel production by the Tanzanian based company was calculated, as shown in Table 8.

[Insert Table 8, here]

4.6 By-Product Production and Revenue

Based on the current operational model of the company after which this case study is modeled, the production of by-products can be separated into those currently produced during the SVO processing stage, and those which could be produced from the proposed biodiesel production process.

4.6.1 SVO Production By-Products

Based on the current SVO production methods of the company, the only saleable by-product from the SVO process is seed cake. This seed cake is converted into briquettes using a briquetting machine, and sold as a firewood substitute to the local populace. From the data supplied in Tables 1, 4 and 6, the quantity of seed cake produced each year, and the overall profit gained from its sale (minus equipment costs) can be calculated, as outlined in Table 9.

[Insert Table 9, here]

4.6.2 Biodiesel Production By-Products

The proposed biodiesel production process outlined in section 3.2 gives rise to two main by-products – glycerine and soap – in addition to the potential capture and reuse of the methanol and magnesium silicate used in the process. In an attempt to maintain a simplified system applicable to a Tanzanian based company just starting out with biodiesel production, it was assumed that only the soap by-product would be utilised. This assumption was based on the extra steps required to purify the glycerine, or those required to capture and reuse either the methanol or the magnesium silicate (FACT Foundation, 2010). Furthermore, based on tests conducted on behalf of the company, the average SVO produced contained a maximum of 6.7% FFAs to be converted to soap in the subsequent transesterification process, whilst in keeping with a conservative approach, it was assumed that only 50% of the biodiesel by-product soap could be successfully captured and sold. Under these assumptions and the biodiesel production process given in section 3.2, the quantity of soap produced each year, and the overall profit gained from its sale can be calculated, as outlined in Table 10.

[Insert Table 10, here]

4.7 Total Cost of Production

With the calculation of the total cost per litre of SVO and subsequently of biodiesel production from Jatropha, the additional calculations of the by-products and their revenues produced during these processes, and the addition of the relevant Tanzanian taxes on diesel, it is possible to compare the total cost of SVO and biodiesel production with their subsequent per litre costs when their by-product revenues are taken into account. This comparison is given in Table 11.

[Insert Table 11, here]

5. Results and Discussion

With the biodiesel production process and its total cost defined (both with and without the utilisation of by-products; see Table 11), it is possible to assess the true financial viability of the production of biodiesel from Jatropha under the given case study conditions. Given that the data for this case study was based on a Tanzanian company, focus was placed on a comparison of the total cost of the Jatropha-based biodiesel under current processing conditions (500 tonnes of Jatropha seeds per year; '500t scenario') and predicted 2014 processing conditions (1000 tonnes of Jatropha seeds per year; '1000t scenario') with Tanzanian and East-African diesel prices, to give a general indication of the financial viability (or not) of the process. This comparison is visualised in Figure 2, showing the high total cost of biodiesel production (US$2.52/L & US$2.11/L) compared with the sale prices of fossil-based diesel in Tanzania and its border countries. At first glance this seems to suggest that based on the total cost of biodiesel production calculated in this case study, general biodiesel production would be financially unviable in all East-African countries (apart from the outlier case of Malawi in the 'biodiesel 1000t' scenario), with the total cost of producing the biodiesel significantly higher than that which it could be sold for at current market prices (assuming no large premium for "sustainable diesel" would be paid to make up for this price deficit).

[Insert Figure 2, in colour, here]

Whilst this initial financial assessment appears to support the overly negative view of Jatropha financial viability such as that held by Kant & Wu (2011), this total cost comparison does not tell the whole story. When the by-product revenue from the briquettes produced during the SVO production alone are taken into account, the total cost of biodiesel production falls to US$1.62/L (US$2.03/L for 'biodiesel 500t' scenario), significantly reduced from the original total cost of production, whilst further inclusion of the revenue from the soap by-product produced from the conversion of SVO to biodiesel further reduces the apparent total cost of biodiesel to US$1.04/L, or US$1.45/L when processing only 500t of Jatropha seeds per year. This gives a total cost of biodiesel (inclusive) that is significantly cheaper than Tanzanian diesel prices in the 1000t scenario, and in the 500t scenario a cost that is on par with many of the neighbouring East-African countries,. The inclusion of the actual revenue generated from by-products (in the case of the briquettes) and the potential by-product revenue (in the case of the soap), suggests that a financially viable Jatropha-based biodiesel production process is possible, when process by-products are utilised for financial gain. This finding is supported by Shumba et al. (2011), who argue that the cultivation of biodiesel alone is economically unattractive but that selling value added products from Jatropha, such as soap, can be economically attractive, as is the current case in Zambia and Zimbabwe (Shumba et al., 2013b).

6. Conclusions

Based on results outlined in this case study, biodiesel production from Jatropha does appear to be financially viable, and is going to become increasingly so as world fuel prices increase due to fossil fuel shortages. However, this financial viability is highly dependent upon the specifics of this case study; i.e. this production is located in Tanzania, with a company focusing on a socially sustainable, smallholder outgrower Jatropha cultivation model under Tanzania-specific operational conditions. More specifically, this case study is based on a Jatropha seed collection model which utilises preexisting hedges on boundary land, which would certainly affect attempts to replicate this study in other countries, or would at the least require a different development or business model to be successful. Furthermore, the Tanzanian Jatropha oil production company is in a position to take advantage of further opportunities of scale due to the large number of untapped Tanzanian smallhold farmers who are growing Jatropha as hedges, whilst avoiding many of the issues outlined by Achten et al. (2009) with regards to large-scale Jatropha plantation growth, which could affect Jatropha biodiesel production firms based on such large-scale plantation models.

It should also be reiterated that the affirmation of financial viability of biodiesel production from Jatropha given in this case specific study, is dependent upon the utilisation of by-products from both the SVO and biodiesel production steps to achieve a biodiesel cost price lower than traditional diesel in East-African markets and thus be financially positive. So whilst studies such as those of Achten et al. (2009) and Kant & Wu (2011) may suggest that certain scenarios of biofuel production from Jatropha are not financially viable (e.g. large plantation models), and that Jatropha might not be the wonder-plant that it has been made out to be in the past, there are still avenues to be explored in the financially viable use of Jatropha as a source for biofuel (biodiesel) production, especially if the process ensures maximum utilisation of by-product production and results in additional benefits to farmers from land and hedge-plants that would otherwise remain unused. This case study takes no stance with regards to the positive euphoria of the potential for Jatropha, or the harsh criticism that the industry has endured, but it certainly hopes that this is a first step towards “clearing the air” and showing that the under the right circumstances biodiesel production from Jatropha can be truly financially viable.

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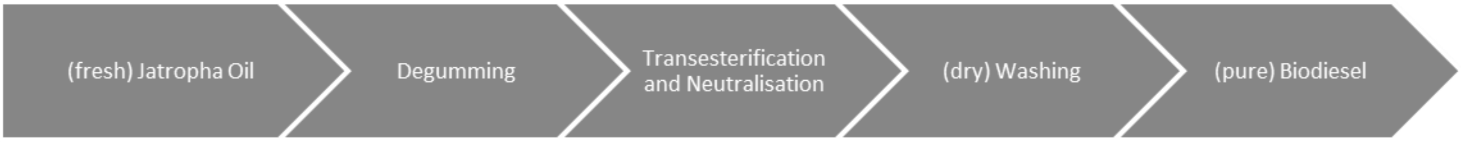

Figure 1 - Modelled Biodiesel Production Process: Jatropha Oil to Biodiesel

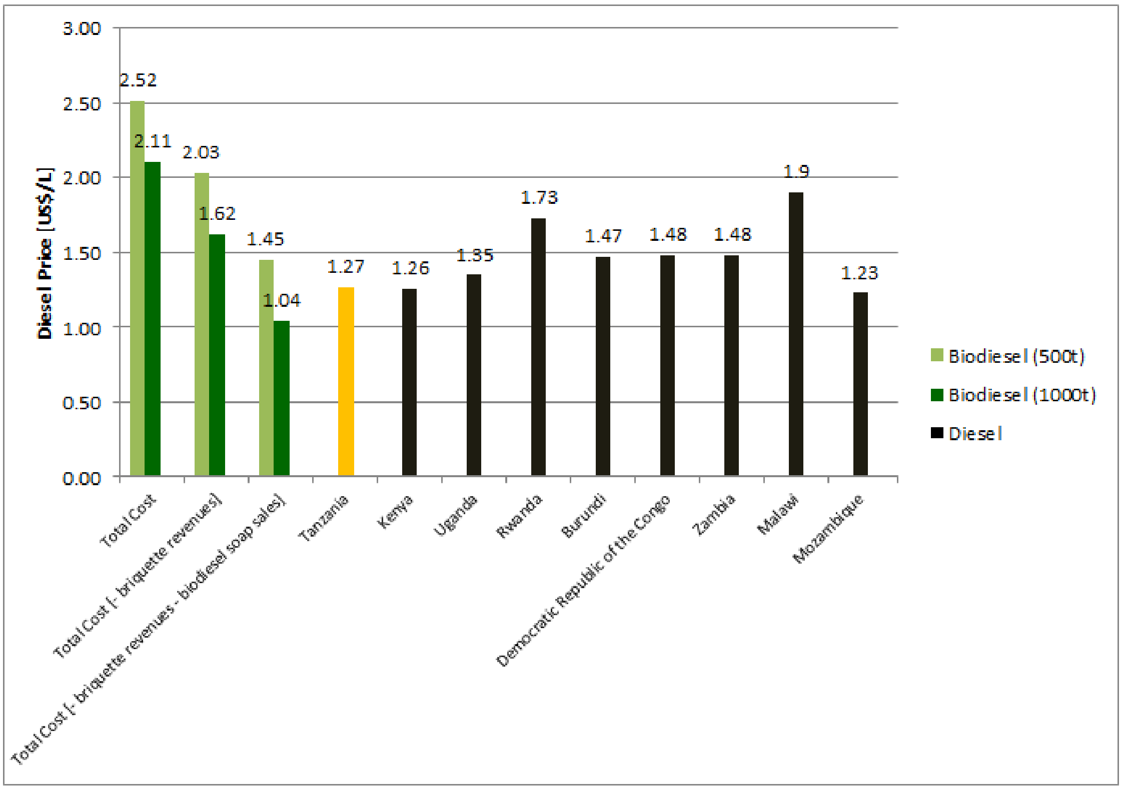

Figure 2 - Comparison of cost of biodiesel production with East-African diesel prices[1]

1 comparing scenarios of 500 tonnes and 1000 tonnes of Jatropha seeds processed into biodiesel per year with diesel prices taken from: http://data.worldbank.org/indicator/EP.PMP.DESL.CD (accessed August 28, 2013).

Table 1 – Company Variables for Producing SVO from Jatropha Seeds

Material Requirement	**Quantity**
Jatropha Seeds [kg/year]	1 000 000 (500 000 in 2012)
Workers [-]	-
Collection of Jatropha Seeds [-]	-
Processing of Jatropha Seeds to SVO [-]	-
SVO Storage and Transportation [-]	-
Quantity of Good (Usable) Seeds [%]	98
Seed to SVO conversion rate [wt%]	22
Seed to seed cake conversion rate [wt%]	70
Seed to sludge conversion rate [wt%]	8
Second pressing conversion rate [wt%]	2
Density of Jatropha SVO [kg/L]	0.90317[1]

1 (Akbar et al., 2009)

Table 2 - Material Requirements for Degumming SVO

Material Requirement	**Quantity**
Heating SVO to 60°C (from room temperature) [kWh/L.SVO]	0.0200704[1]
Phosphoric Acid [kg/L.SVO]	0.000090317
Stirring Requirements [hours]	0.5
Water [L/L.SVO]	0.0180634
Heating SVO mixture to 80°C (from 60°C) [kWh/L.SVO]	0.020071[1]

1 where the average room temperature of the stored SVO is 20C, and the Specific Heat Capacity of Jatropha oil is taken from http://www.scientificjournals.org/journals2007/articles/1174.pdf (accessed August 27, 2013) at 2000J/kg.K.

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Table 3 - Material Requirements for Transesterification (& Neutralisation) of SVO

Material Requirement	**Quantity**
Potassium Hydroxide (KOH) [kg/L.SVO]	0.0180165
Methanol [L/L.SVO]	0.22
Stirring Requirements for KOH + methanol [hours]	0.1667
Heating mixture to 60°C (from room temperature) [kWh/L.SVO]	0.000163028[1]
Stirring Requirements for total mixture [hours]	0.1667

1 where the average room temperature of the stored SVO is 20C, and the Specific Heat Capacity of Jatropha oil is taken from http://www.scientificjournals.org/journals2007/articles/1174.pdf (accessed August 27, 2013) at 2000J/kg.K, whilst it is assumed total mixture behaves roughly like SVO in terms of its Specific Heat Capacity.

Table 4 – SVO production unit quantities and costs

Material	Value
Currency Conversion from TZS to USD [TZS/USD]	1600
General Rate of Cost Increase [%/year]	1
Company purchase price of Jatropha seeds [US$/kg]	0.1875
Daily Wage of Unskilled Worker (high-end); 8 hour day [US$/day]	4.923
Cost of Seed Collection [US$/tonne of seeds]	61.84
Cost of Seed to SVO Processing [US$/tonne of seeds]	38.48
Cost of SVO Storage and Transportation [US$/tonne of seeds]	3.83
Selling Price of Briquettes (SVO Production By-Products) [US$/kg]	0.1875

Table 5 – Biodiesel production unit costs

Required Material	Cost
Cost of electricity [US$/kWh]	0.12[1]
Cost of phosphoric acid (H3PO4) [US$/kg]	4[2]
Cost of water [US$/L]	0.0002[3]
Cost of KOH [US$/kg]	2[4]
Cost of methanol [US$/L]	0.4[5]
Cost of magnesium silicate [US$/kg]	4[6]

1 http://sabahionline.com/en_GB/articles/hoa/articles/features/2012/03/06/feature-01 (accessed August 27, 2013); 2 a rather conservative value when compared to world averages: http://www.alibaba.com/product-gs/920661422/Price_for_Phosphoric_acid_85_CAS.html (accessed August 27, 2013); 3 http://www.maji.go.tz/modules/documents/index.php?action=downloadfile&filename=2009%20Water%20Sector%20Status%20Report.pdf&directory=Reports& (accessed August 27, 2013); 4 taking highest sale price to ensure a conservative overall production cost: http://www.alibaba.com/product-gs/606018044/95_90_Potassium_Hydroxide_Price.html (accessed August 27, 2013); 5 taking a conservative price, higher than available averages: http://emsh-ngtech.com/methanol/methanol-pricing (accessed August 27, 2013); 6 taking highest sale price to ensure a conservative overall production cost: http://www.alibaba.com/product-gs/885605453/magnesium_silicate_powder.html?s=p (accessed August 27, 2013).

Table 6 – Equipment Costs

Equipment	Cost	Cost per year
Briquetting machine [US$]	2500[1]	500
Biodiesel production system [US$]	10000[2]	2000

1 assuming a slightly more expensive model would be required a conservative value compared to the US$2000 given by http://www.gvepinternational.org/sites/default/files/briquette_businesses_in_uganda.pdf (accessed August 22, 2013) was used;
2 this value was taken by analysing the available models of a roughly suitable daily SVO processing capacity (http://www.evolutionbiodieselkits.com/farm-boss-biodiesel-processor-specs.php, http://www.fermentor.co.in/fermentor-bioreactor-mass-flow-controller.html, http://www.extremebiodiesel.com/main/biodiesel-products/, http://www.alibaba.com/product-gs/873974186/500L_waste_oil_machine_biodiesel_processor.html) (accessed August 22, 2013) and then taking a more conservative value to account for the rarity of such systems in Tanzania and the potentially need for capacity expansion.

Table 7 – Cost of SVO Production

Process Step	**Cost per litre SVO produced (500t scenario) [US$/L]**	**Cost per litre SVO produced (1000t scenario) [US$/L]**
Company overheads	0.7557724	0.3778862
Purchase of seeds	0.7334481	0.7334481
Cost of workers	0.000019	0.0000094
Collection costs	0.2419131	0.2419131
Processing costs	0.1505291	0.1505291
SVO storage & transport	0.0149796	0.0149796
Total Cost of SVO	**1.897**	**1.519**

Table 8 – Cost of Biodiesel Production

Process Step	Cost per litre biodiesel produced (500t scenario) [US$/L]	Cost per litre biodiesel produced (1000t scenario) [US$/L]
SVO Production		
SVO	1.9965[1]	1.5987[1]
Degumming		
Heating SVO to 60°C	0.0024085	0.0024085
Phosphoric acid (H3PO4)	0.00038028	0.00038028
Stirring requirements	0.00045654	0.00045654
Water	0.0000037717	0.0000037717
Heating mixture to 80°C	0.0024085	0.0024085
Transesterification (& Neutralisation)		
Minimum required catalyst (KOH)	0.037929	0.037929
Methanol	0.092631	0.092631
Stirring requirements	0.00030436	0.00015128
Heating mixture to 60°C	0.000019563	0.000019563
Stirring requirements	0.00030436	0.00015128
Washing		
Magnesium Silicate	0.0352	0.0352
Equipment Costs		
Biodiesel production system	0.0162606	0.0081303
Total Cost of Biodiesel Production[2]	**2.1852**	**1.7786**

1 given the assumed conversion rate of 95% by volume of SVO to biodiesel (see section 3.2.5), approximately 1.053 litres of SVO is required to produce 1 litre of biodiesel; 2 before the addition of Tanzanian tax on biodiesel.

Table 9 – By-Product Production from SVO Process

Variable	500t Scenario	1000t Scenario
Seed cake [kg/year]	336 140	672 280
Briquettes [kg/year]	336 140[1]	672 280[1]
Selling Price of Briquettes [US$/kg]	0.1875	0.1875
Cost of briquetting machine [US$/year]	500	500
Total Revenue [US$/year]	**62 526**[2]	**125 553**[2]

1 this assumption of 100% conversion of seed cake to briquettes is based on the current operations of the company which assumes no wastage; 2 current practice has seen no saturation of the local fuel-source market with the briquettes, thus allowing the assumption of the sale of all briquettes at the assumed selling price.

Table 10 – By-Product Production from Biodiesel Process

Variable	500t Scenario	1000t Scenario
Maximum soap conversion potential from SVO [%]	6.7	6.7
Soap recovery rate [%]	50	50
Total SVO converted to biodiesel [L/year]	136 284	272 569
Selling price of soap [US$/kg]	15.625[1]	15.625[1]
Total Revenue [US$/year]	**71 337**	**142 673**

1 the by-product soap is typically sold as small 100g bars for laundry washing, however, using the KOH catalyst produces liquid soap so it is assumed the this liquid soap can be sold at the same price as laundry soap bars.

Table 11 – Total Cost of SVO and Biodiesel

Scenario	**Cost of SVO (500t scenario) [US$/L]**	**Cost of Biodiesel (500t scenario)[1] [US$/L]**	**Cost of SVO (1000t scenario) [US$/L]**	**Cost of Biodiesel (1000t scenario)[1] [US$/L]**
Total Cost	1.8967	2.5165	1.5189	2.1098
Total Cost [- briquette revenues]	1.4379	2.0336	1.0581	1.625
Total Cost [- briquette revenues - biodiesel soap sales]	-	1.4536	-	1.045

1 where the tax on diesel in Tanzania is 530 TZS/L or approximately 0.33125 US$/L (www.pwc.com/tz/en/pdf/pwc-tanzania-budget-2013--14--summary.pdf) and is included in addition to the cost of biodiesel production to provide the total cost.