AN ASSESSMENT OF THE ECONOMIC SUSTAINABILITY OF *JATROPHA*-BASED BIODIESEL INITIATIVES: IMPLICATIONS FOR LABOUR AND RURAL LIVELIHOODS

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Abstract

Crude oil is the single most utilized resource for energy and global demand is expected to increase 40 – 50 % that of current levels by the years 2025 to 2030. One renewable energy alternative is liquid biofuel, which currently is one of the fastest-growing markets for agricultural products globally. Whilst reducing environmental impact is well appreciated in developed nations, powerful drivers for stimulating the biofuel market in poorer regions of the world are socio-economic in nature. A plant of great contemporary importance is *Jatropha curcas* L. (*Jatropha*) which produces inedible oil seeds with good properties for biodiesel refinement. Promoters of *Jatropha* motivate that the benefits associated with this biodiesel feedstock are a solution to many of the developing world's socio-economic problems as it generates high levels of rural employment, improves national balance of trade and stimulates both agricultural and non-agricultural sectors associated with the *Jatropha*-biodiesel production chain. *Jatropha* needs to be pruned often initially to establish higher yields, it isn't at present harvested mechanically, it requires pesticide application and weeding, and the labour requirement during establishment is high. This labour requirement may contribute greatly to rural employment but at a significant labour cost which may undermine the profitability of growing *Jatropha*. This research aims to assess the economic sustainability of *Jatropha*-based biodiesel production as a suitable driver for rural development and in particular by modelling the maximum potential financial returns for labour.

A spreadsheet based financial model was developed from life-cycle economic analysis of the *Jatropha*-biodiesel production chain to determine if income can support labour wages in southern Africa and India, under local wage legislation, at different yield, production cost and fuel price scenarios. The main assumption of the model was that the biodiesel sales price is proportional to the prevailing petro-diesel price. During the execution of the study it became apparent that the application of the conceptual model is strongest for India however, for comparative reasons, South Africa and Zambia were included. Results suggest that

minimum legal wages in South Africa are too high to support production at the current fuel price. India and Zambia have the potential to generate profits but under specific circumstances; which are a complex function dominated by yield, labour wages, the petroleum-diesel price and the market opportunities for by-products.

Financial capital is among many complex and almost unquantifiable assets to rural livelihoods, many of which compete for labour opportunity. In the 1990's a sustainable livelihoods framework was developed by the UK Department for International Development (DFID). At the core of the framework is the "belief that people require a range of assets to achieve positive livelihood outcomes", categorized into five different capital forms, namely; natural, human, financial, social and physical. The impacts that the biofuel industry can have on rural livelihoods in southern Africa and India can be considerable.

Declaration

I declare that this dissertation is my own unaided work, except where acknowledged. No part of this dissertation has previously been submitted for any degree or examination to any other University.

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Chapter 1: Introduction

The annual global demand for energy is in excess of 380 x 10^9 gigajoules (BP, 2004) of which the transport industry is responsible for approximately 20 % of consumed energy (WBCSD & IEA, 2004). Crude oil is the single most utilized resource for energy (EIA, 2005) and global demand is expected to increase 40 – 50 % that of current levels by the years 2025 (Johnston & Halloway, 2007; Rooney *et al*., 2007) to 2030 (IEA, 2008). The rising demand for oil, speculation of diminishing reserves, fuel price instability, the consequent growing need for energy security and the realization of the environmental impact of fossil fuel dependence has incited global efforts to develop capacity for alternate sources of energy provision (IEA, 2008).

Liquid biofuel, when sustainably derived from biomass, is one such renewable energy alternative. The potential for reducing anthropogenic greenhouse gas (GHG) emissions is an international driver for the utilization of liquid biofuel in the transport sector; however, the importance of this driver in domestic markets is incongruent between developed and developing nations (Haywood *et al*., 2008; von Maltitz & Brent, 2008; von Maltitz *et al*., 2009). Whilst reducing environmental impact is well appreciated in the developed world, powerful drivers for stimulating the biofuel market in poorer regions of the world are socio-economic in nature. The lack of modern energy infrastructure in the developing world mirrors low economic performances and hinders the economic development in those regions, the problem being most evident in rural areas (Carter & May, 1999; Cousins, 1999).

The agricultural sector has been proven to be four times more successful in poverty reduction and improving rural livelihoods than other sectors of economic activity (World Bank, 2008). Liquid biofuel is currently one of the fastest-growing markets for agricultural products globally (Fairless, 2007; Matthews, 2007); however, an increasing number of publications urge caution when developing a biofuel economy due to risks of unsustainable practice (Gallagher, 2008; Royal Society, 2008; Searchinger *et al*., 2008). Such articles cite concerns over inconsistent methodologies for quantifying biofuel life-cycle GHG balances, conflict with food products for land and market preference, unsustainable indirect effects of associated land-use changes, poor feedstock production efficiencies, higher energy and financial costs of production compared to petroleum-feedstock, and an overestimation of potential productivity and socio-economic performance.

One feedstock of contemporary importance is *Jatropha curcas* L., (henceforth referred to as *Jatropha*), which produces inedible oil seeds with good properties for biodiesel refinement, meeting both American and European quality standards (Azam *et al*., 2005; Tiwari *et al*., 2007). An important by-product to production is the *Jatropha* seedcake which can be used as fertilizer and/or, along with additional organic waste products of feedstock production, can be digested to produce biogas (methane) (Lopez *et al*., 1997; Staubmann *et al*., 1997; Gubitz *et al*., 1999; Radhakrishna, 2007; Tewari, 2007).

Due to claims of high yields and wide environmental tolerances (Francis *et al*., 2005; Jongschaap *et al*., 2007), over 900,000 ha have been planted globally to *Jatropha*, with anticipated future plantings at over one million hectares per year (GEXSI, 2008a). Sub-Saharan Africa and South Asia are regions making strong investments in the *Jatropha*-biodiesel industry, with significant developments already underway in Zambia and India, as examples. Promoters of *Jatropha* motivate that the benefits associated with this biodiesel feedstock are a solution to many of the developing world's socio-economic problems (Jones & Miller, 1992; Newsletter Plant Oil, 1993; GTZ, 1995; GTZ/Rockefeller Foundation, 1995; Heller, 1996; Henning, 1996; Zimbabwe Biomass News, 1996; Gubitz *et al*., 1997; Openshaw, 2000; Francis *et al*., 2005; GEXSI, 2008b) as it generates high levels of rural employment, improves national balance of trade and stimulates both agricultural and non-agricultural sectors associated with the *Jatropha*-biodiesel production chain. The plant itself is believed to prevent and control soil erosion and reclaim agricultural wastelands or it can be used as a living fence for excluding livestock from food crops as *Jatropha* is unpalatable (Heller, 1996; Henning, 1997; Openshaw, 2000; Francis *et al*., 2005; Henning, 2006).

Rationale, Aims and Objectives

Much of the earlier literature suggests that *Jatropha* is a hardy crop that can be grown with very little or no maintenance inputs (Jones & Miller, 1992; Heller, 1996; Henning, 1996; Openshaw, 2000). More recent experience suggests that *Jatropha* responds far more favourably to management input; it needs to be pruned often initially to establish higher yields, it cannot at present be harvested mechanically, it requires pesticide application and weeding, and the labour requirement during establishment is high (Francis *et al*., 2005; Jongschaap *et al*., 2007; Achten *et al*., 2008). This labour requirement contributes greatly to rural employment but at a significant labour cost which may undermine the profitability of growing *Jatropha*. For *Jatropha* cultivation to reduce poverty and improve rural livelihoods, the biodiesel production chain needs to be profitable enough to provide an income for labour that is both economically sustainable and poverty reducing. The maximum wage rate for labour is governed by the production efficiency of the chosen feedstock and the price at which biodiesel can be sold. The global hype surrounding this crop combined with a relatively poor understanding of its agronomy and unpredictable yields has the potential for unsustainable practice of biodiesel production in the regions where it is being promoted.

This research aims to assess the sustainability of *Jatropha*-based biodiesel production as a suitable driver for rural development, from a regional micro-economic perspective, and in particular by evaluating the maximum potential financial returns for labour. The regions of concern are those with developing economies in both the tropics and sub-tropics, already mentioned as important feedstock producers for the biodiesel industry, namely; sub-Saharan Africa and South Asia, in countries like Zambia and India.

The aim of this research is addressed in two ways; by reviewing the appropriate literature on the *Jatropha*-biodiesel production chain and then by considering the best available regional data for generalizing the absolute costs of production to model the maximum returns for labour. More specific objectives have been defined, namely to:

1. obtain a general understanding of the economics at different spatial scales of biodiesel production by reviewing literature on the *Jatropha*-biodiesel production chain, the different types of farming models and plantation management practices for *Jatropha*;

2. develop a model specifically for determining the maximum returns for labour at different wholesale prices, production costs and yield scenarios; and

3. discuss the merit of using specific financial returns for labour as a proxy for general economic sustainability assessments.

During the execution of the study it became apparent that the application of the conceptual model is strongest for India; however, for comparative reasons, South Africa and Zambia were included. The rationale for the selection of these three countries is developed in Chapter 4. The model determines financial returns for labour in the form of wages and cash income to small-scale farmers. The study does not address economic gender inequalities nor does it attempt a broad assessment of rural development. Although important aspects of rural livelihoods are discussed, the focus of the economic assessment is biased towards labour and the contribution made by *Jatropha* cultivation to the financial status of rural households.

Chapter 2: Literature Review

2.1. What are Biofuels?

Liquid biofuels are generally used in the context of the transport sector, being surrogates or supplements for petroleum fuels, either petrol or diesel, derived from biomass. Liquid biofuels for the transport sector are bio-ethanol and biodiesel, replacing or in mixture with petrol and diesel respectively. Bio-ethanol is an alcohol produced from plant carbohydrates such as sugar and starch. Usually used as a blend in relatively low ratios with petroleum, typically up to 10 % in blend composition (E10), engines can potentially run on bio-ethanol entirely (E100); however, this requires substantive modifications, and bio-ethanol only has a 70 % calorific equivalence to petroleum by volume (Elsayed *et al*., 2003). Biodiesel has greater potential as a fossil fuel substitute (i.e. B100). Produced from virgin vegetable oils, used cooking oil or tallow, biodiesel has a much greater calorific equivalence to petro-diesel (93 % by volume) compared with bioethanol to petrol (Elsayed *et al*., 2003). Relatively unrestricted to oilseed selection, preferential feedstock species are usually selected on criteria of production efficiency and not by incompatibility. The first diesel engine was designed to run on pure peanut oil and plant oils can be used even without refinement in older unmodified diesel vehicle engines or low-speed stationery motors such as generators and pumps (FACT Foundation, 2009). Oil refinement is necessary for biodiesel use in modern transportation and involves a process called transesterification which is discussed in section 2.3.2.

The types of feedstock commercially used for both bioethanol and biodiesel are typically agricultural crops, such as grains and sugarcane for the former, and edible oilseeds and groundnuts for the latter. These biofuels are termed first generation, their technologies exist and specific feedstocks are already being commercially produced for petroleum blends. Newer technologies are being tested which will allow for a wider range in feedstock utilization (IEA, 2008), extending to crop residues, grasses, algae, and wood. These technologies are termed second generation and include among them lignocellulosic digestion, fast pyrolysis and Fischer-Tropsch synthetic fuel (Batidzirai *et al*., 2006; E4Tech, 2008). However, in general, biomass utilization for energy is as old as mankind and many poorer economies still to this day rely, to a large proportion, on biomass for fuel. This study; however, within the broader field of bioenergy, looks more narrowly at first generation liquid biofuels for the transport sector and specifically biodiesel produced from *Jatropha* oilseeds.

2.2. *Jatropha curcas* L.

Jatropha produces oil seeds with good properties for biodiesel refinement. It is claimed that this crop performs well in semi-arid environments and under marginal soil conditions (Jones & Miller, 1992; Heller, 1996; Henning, 1996; Openshaw, 2000; Francis *et al*., 2005; Jongschaap *et al*., 2007) and great interest is being shown in the propagation of this plant in sub-tropical regions of the world for oil expression. Promoters and investors motivate that the benefits associated with this biodiesel feedstock are a solution to many of the developing world's socio-economic problems (Jones & Miller, 1992; Newsletter Plant Oil, 1993; GTZ, 1995; GTZ/Rockefeller Foundation, 1995; Heller, 1996; Henning, 1996; Zimbabwe Biomass News, 1996; Gubitz *et al*., 1997; Openshaw, 2000; Francis *et al*., 2005; GEXSI, 2008b). Based on those publications *Jatropha* production is being promoted as a powerful opportunity for employment, a commodity for foreign exchange, a stimulus for improving overall agricultural output, and a catalyst for development in non-agricultural sectors associated with the *Jatropha*-biodiesel production-chain. Employment in both the agricultural and non-agricultural sectors will most likely be the most powerful proponent for *Jatropha* cultivation in developing countries, such as India and Zambia.

Botanical Description

Jatropha, also known by its common name "Physic Nut", belonging to the Euphorbiaceae family, is a deciduous large shrub or small tree that grows to a height of up to 7 m displaying articulated growth (Heller, 1996). Individuals can live up to 50 years developing a relatively light wood in density of between 0.29 (Achten *et al*., 2010) and 0.37 g.cm^{-3} (Benge, 2006). Believed to have originated from Mexico and Central America (Heller, 1996; Rao *et al*., 2008; Sujatha *et al*., 2008), natural distributions of the species are scattered pantropically (Jongschaap *et al*., 2007) from west to east as far as the islands of Fiji (International Council for Research in Agroforestry, accessed online 02/07/2010). The stem and branches are light grey-green in colour and the plant is stem-succulent (Maes *et al*., 2009a), tolerating dry conditions by dropping its leaves. Leaves are dark green, smooth, 4 – 6 lobed and 10 – 15 cm in both length and breadth, arranged alternately (Heller, 1996). Damaging the shoots or branches or removing a leaf and petiole presents white sticky latex, characteristic to the family. *Jatropha* typically only flowers during the wet season (Raju & Ezradanam, 2002) but the duration of flowering can be extended annually by irrigation (Heller, 1996). Pollinated by insects (Heller, 1996), inflorescences are situated at the terminus of the branches and are monoecious (Heller, 1996); the ratio between male and female flowers ranges from 13:1(Tewari, 2007) to 29:1(Raju & Ezradanam, 2002), decreasing with the age of the tree (Prakash *et al*., 2007). Fruits are ellipsoid in shape (Tewari, 2007), approximately 40 mm in length and mature from green to yellow-brown to black and dry, and fruiting is asynchronous. Each fruit husk contains usually three black seeds rich in oil (27 – 40 % by mass of the seed) but also, in many provenances, containing toxins, predominantly phorbol esters but also curcin, trypsin inhibitors, lectins and phytates (Aderibigbe *et al*., 1997; Aregheore *et al*., 1997; Makkar *et al*., 1997; Makkar & Becker, 1997; Makkar *et al*., 1998a; Makkar *et al*., 1998b; Aregheore *et al*., 2003; Martinez-Herrera *et al*., 2006; Makkar *et al*., 2007), making the seeds inedible for humans and animals. Seeds consist of a hard coating or shell which accounts for 37 % of seed mass and 63 % being the seed kernel; golden-white and oil-containing. The plant forms a deep taproot when cultivated from seed, but the plant can easily be reproduced vegetatively from cuttings. Coarse roots also spread laterally; usually four peripheral roots emerge from the seedling in addition to the taproot (Heller, 1996).

From top-left to bottom right: Jatropha tree (Tree Oils India Limited, accessed online 02/07/2010); and plantations (International Land Coalition, accessed online 02/07/2010) displaying well pruned architecture for harvesting; leaves and inflorescences (photo by P. Latham); fruit (Echo Bookstore, accessed online 02/07/2010); fruiting asynchrony (Jatropha Investment Fund, accessed online 02/07/2010); and fruit at different stages of maturity with seeds (Dilligent Tanzania Ltd.).

2.3. *Jatropha*-Biodiesel Production Chain

The first stage in producing *Jatropha*-biodiesel is growing feedstock. The inputs for this stage include; land, labour, technical expertise, and depending on management choices; machinery, utilities, fertilizer, pesticides, herbicides, irrigation and miscellaneous raw materials. Outputs are *Jatropha* seeds and biomass by-products. The second stage, and the first in the chain of processing feedstock, is oil extraction. The main inputs are feedstock, infrastructure, and energy, the product is unrefined *Jatropha* oil and seedcake is an important by-product. Oil refining is the third stage, a process called transesterification, which produces *Jatropha*-biodiesel and a glycerine by-product. Inputs include *Jatropha* oil, infrastructure, raw materials and energy. The final stage is distribution of *Jatropha*-biodiesel to the end-user. Figure 2.1 displays the series of stages in producing *Jatropha*-biodiesel.

2.3.1. Using *Jatropha* Oil

Jatropha oil can be used as both a refined and an unrefined resource for energy production. *Jatropha* oil is refined through the transesterification process to produce *Jatropha* methyl-ester (JME), essentially biodiesel, which is a product suitable for petro-diesel substitution in high speed diesel engines with the least, if any, modification necessary. Prasad *et al*. (2000) determine that JME performs similarly to petro-diesel and results in little or no additional abrasion to conventional diesel-engines (Kaul *et al*., 2007). Glycerine is a by-product of the transesterification process which is used predominantly in the cosmetic and pharmaceutical industries (Bender, 1999), but can also be used as a co-product to biodiesel refinement; recycled as an energy input improving the net energy balance by reducing fossil fuel input, as it can be combusted to liberate heat energy (Achten *et al*., 2008).

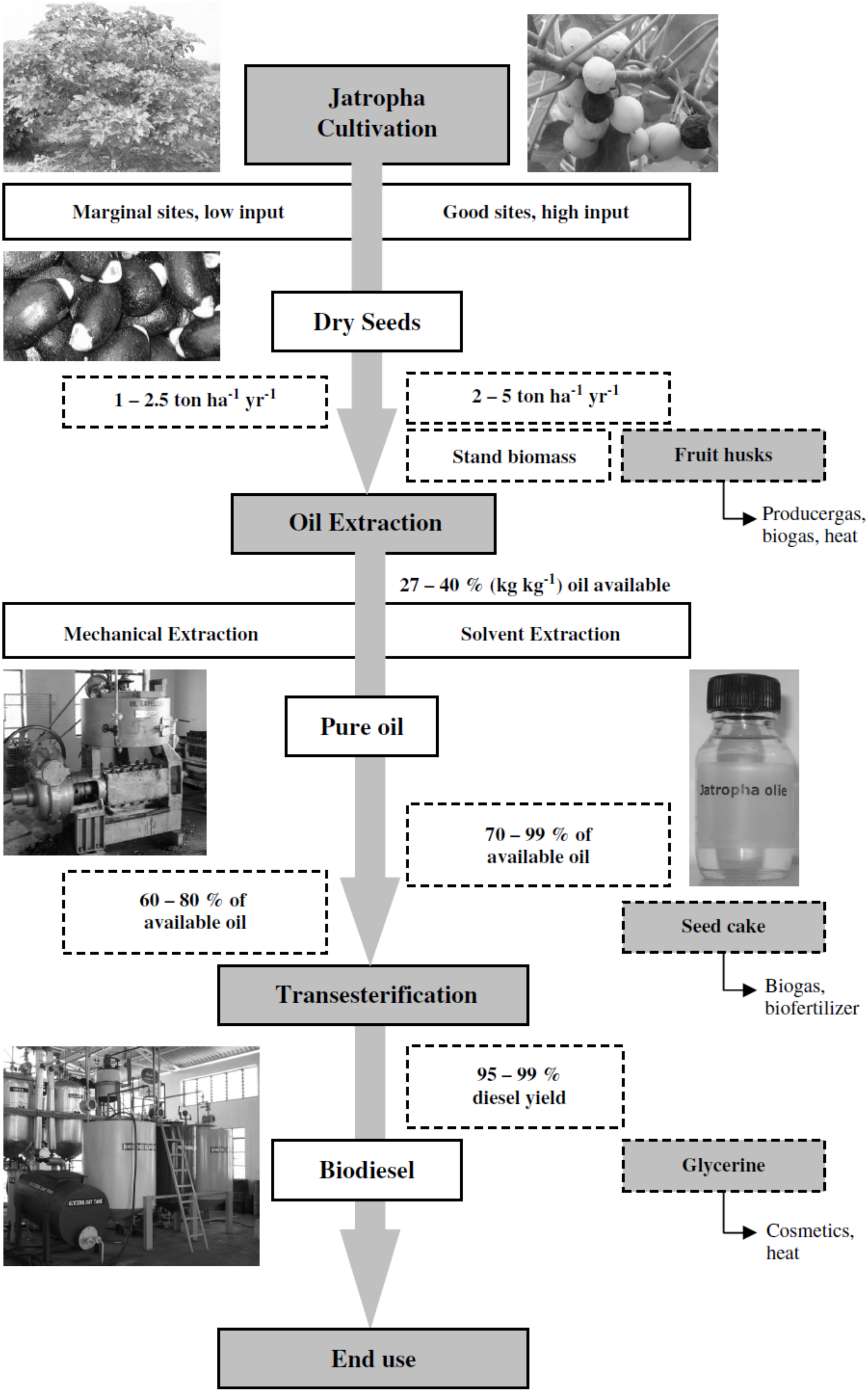

Figure 2.1: The Jatropha-biodiesel production chain. Source: Achten et al., 2007.

Unrefined *Jatropha* oil is more suitable for use in diesel engines which run at constant speeds, such as generators and pumps and possibly even quite efficiently in tractor engines (FACT Foundation, 2009). The most significant factor limiting the use of *Jatropha* oil is its viscosity (FACT Foundation, 2009) and also the high degree of natural variability in the quality of the oil (Table 2.1).

Table 2.1: *Jatropha* oil composition and quality

	Unit	Min	Max	Mean	[s.d.]	n
density	g cm^{-3}	0.860	0.933	0.914	[0.018]	13
calorific value	MJ kg^{-1}	37.83	42.05	39.63	[1.52]	9
pour point	°C			-3	[N/A]	2
cloud point	°C			2	[N/A]	1
flash point	°C	210	240	235	[11]	7
cetane value		38.0	51.0	46.3	[6.2]	4
saponification number	mg g^{-1}	102.9	209.0	182.8	[34.3]	8
viscosity at 30 °C	cSt	37.00	54.80	46.82	[7.24]	7
free fatty acids	% (w/w)	0.18	3.40	2.18	[1.46]	4
unsaponifiable	% (w/w)	0.79	3.80	2.03	[1.57]	5
iodine number	mg g^{-1}	92	112	101	[7]	8
acid number	mg KOH g^{-1}	0.92	6.16	3.71	[2.17]	4
monoglycerides	% (w/w)			1.7	[N/A]	1
diglycerides	% (w/w)	2.5	2.7	2.6	[N/A]	2
triglycerides	% (w/w)	88.20	97.30	92.75	[N/A]	2
carbon residue	% (w/w)	0.07	0.64	0.38	[0.29]	3
sulphur content	% (w/w)	0	0.130	0.065	[N/A]	2

s.d. = standard deviation; n = no. of observations. Taken from Achten et al. (2008), sources: Banerji et al., 1985; Kandpal & Madan, 1995; Foidl et al., 1996; Vaitillingom & Liennard, 1997; Zamora et al., 1997; Gubitz et al., 1999; Augustus et al., 2002; Kumar et al., 2003; Pramanik, 2003; Akintayo, 2004; Forson et al., 2004; Kpoviessi et al., 2004; Chitra et al., 2005; Adebowale & Adedire, 2006; Reddy & Ramesh, 2006.

Achten *et al*. (2008) attribute this variability in oil quality to the combination of environmental conditions and genetics. *Jatropha* is a relatively wild species in the sense that very limited selective breeding has been undertaken (Achten *et al*., 2010) and it is cultivated across a wide range of environments; hence, experience domesticating the crop is varied. Unrefined *Jatropha* oil can also be blended with petro-diesel and used as a transport fuel; however, this, in all cases, results in increased smoke levels and higher soot and carbon monoxide emissions compared with unblended petro-diesel (Kumar *et al*., 2003), and does not achieve the quality and performance standards of JME.

Achten *et al*. (2008) conclude that JME is in general a better performing biofuel than unrefined *Jatropha* oil, used independently or blended with petro-diesel; however, the virtues of using *Jatropha* oil must not be underrated as it may prove to be a more readily available and cost-efficient fuel, particularly in its application in rural areas. It is easier to modify diesel engines which use older technologies (FACT Foundation, 2009), such as tractors and old four-wheel-drive vehicles, to run more efficiently on plant oil than what has been demonstrated from its poor performance in contemporary motors (Ma & Hanna, 1999; Kumar *et al*., 2003; Barnwal & Sharma, 2005; FACT Foundation, 2009; Meher *et al*., 2006; Agarwal, 2007). *Jatropha* oil can be used in generators for rural electrification (Gmünder *et al*., 2010), in pumps for irrigation, as a substitute to kerosene for lighting and also for general household heat generation (FACT Foundation, 2009). It can also be used to produce soap (FACT Foundation, 2009) and as a biocide for insects, molluscs, fungi and nematodes (Shanker & Dhyani, 2006).

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2.3.2. Transesterification

JME meets most European (EN 14214:2003 & DIN V 51606) and American (ASTM D6751) diesel standards (Azam *et al*., 2005; Tiwari *et al*., 2007)(Table 2.2). The mean viscosity based on those sources for Table 2.2 is too high by European standards but within the acceptable range of American diesels. The mean viscosity for JME is quite considerably lower than unrefined *Jatropha* oil, statistically significant with 99 % confidence ($p < 0.001$; d.f. = 7; one-tailed t-test for independent samples of unequal sample sizes and variance). In addition the standard deviation on the mean viscosity of JME, along with the vast majority of other fuel qualities, is smaller than the estimated variance on unrefined *Jatropha* oil. Transesterification greatly improves the quality of oil derived from *Jatropha* as a transportation fuel.

Transesterification is a catalyzed chemical reaction in which plant oil reacts with an alcohol to produce fatty acid alkyl esters (e.g. fatty acid methyl ester or FAME) and glycerol. The main constituent of plant oil is triglycerides which comprise three long hydrocarbon chains (fatty acids) bound to a glycerol molecule by ester bonds. In the presence of an alcohol, in the majority of cases methanol, and either an alkali- or acid-catalyst, usually an alkaline compound like sodium hydroxide (NaOH), the ester bonds are broken and then reformed between the free fatty acids and the alcohol and glycerol is liberated. Methanol is typically used as it is low in price and needed in high quantities, as an excess of reagent is required for greater conversion (Zhang *et al*., 2003a). Acid-catalysed reactions are favoured less due to the slower reaction time (Freedman *et al*., 1984). The required ratio between reagent and reactant and the optimal amount of catalyst varies as a result of the differences between the feedstocks used, and within a feedstock, as a result of the genetic diversity between individuals and the environments in which they are grown (Achten *et al*., 2008). The optimum for *Jatropha* oil has been proposed by Chitra *et al*. (2005) whereby the molar ratio between methanol and oil is 5.5:1, representing approximately 20 % methanol by mass *Jatropha* oil, using 1 % (by mass *Jatropha* oil) NaOH at 60 °C. Maximum conversion is achieved after 90 minutes, but this rate, and the optimal inputs of reagent and catalyst, depends on the composition of free fatty acids in *Jatropha* oil, as the catalyst becomes sensitive to high free fatty acid numbers (Tiwari *et al*., 2007). In cases where the constituent of free fatty acid in the feedstock is higher, for example used cooking oil (Lepper & Friesenhagen, 1986), an acid catalyzed reaction may be necessary as sulphuric acid, for example, although slower in reaction rate, is insensitive to free fatty acids (Zhang *et al*., 2003a).

Table 2.2: Fuel quality of JME compared to European (EN 14214:2003), German (DIN V 51606) and American (ASTM D 6751) standards.

	Unit	Min	Max	Mean	[s.d.]	n	EN 14214:2003	DIN V 51606	ASTM D6751
density	g cm^{-3}	0.864	0.880	0.875	[0.007]	6	0.86 - 0.90	0.87 - 0.90	
calorific value	MJ kg^{-1}	38.45	41.00	39.65	[1.28]	4			
flash point	°C	170	192	186	[11]	4	min 120	min 110	min 130
cetane value		50.0	56.1	52.3	[2.3]	5	min 51	min 49	min 47
saponification number	mg g^{-1}			202.6	[N/A]	1			
viscosity at 30 C	cSt	4.84	5.65	5.11	[0.47]	3	3.5 - 5.0 [a]	3.5 - 5.0 [a]	1.9 - 6.0 [a]
iodine number	mg g^{-1}	93.0	106.0	99.5	[N/A]	2	max 120	max 115	max 115
acid number	mg KOH g^{-1}	0.06	0.50	0.27	[0.22]	3	max 0.5	max 0.5	max 0.5
monoglycerides	% (w/w)			0.24	[N/A]	1	max 0.8	max 0.8	
diglycerides	% (w/w)			0.07	[N/A]	1	max 0.2	max 0.4	
triglycerides	% (w/w)			n.d.		0	max 0.2	max 0.4	
carbon residue	% (w/w)	0.02	0.50	0.18	0.27	3	max 0.3	max 0.3	max 0.05
sulphur content	% (w/w)			0.0036	[N/A]	1	max 0.01	max 0.01	max 0.015 [b]
sulphated ash	% (w/w)	0.005	0.010	0.013	0.002	4	max 0.02	max 0.03	max 0.02
methyl ester content	% (w/w)			99.6	[N/A]	1	min 96.5		
methanol	% (w/w)	0.060	0.090	0.075	[N/A]	2	max 0.2	max 0.2	
water	% (w/w)	0.070	0.100	0.085	[N/A]	1	max 0.5	max 0.5	max 0.5
free glycerol	% (w/w)	0.015	0.030	0.0225	[N/A]	2	max 0.02	max 0.02	max 0.02
total glycerol	% (w/w)	0.088	0.100	0.094	[N/A]	2	max 0.25	max 0.25	max 0.24

s.d. = standard deviation; n = no. of observations; n.d. = no data. a = mean viscosity at 40 °C (mm^2 s^{-1}). Francis et al. (2005) report 4.2 mm^2 s^{-1} at 40 °C for JME. b = maximum 0.015 % for S 15 Grade and maximum 0.05 % for S 500 Grade. Taken from Achten et al. (2008), sources: Banerji et al., 1985; Kandpal & Madan, 1995; Foidl et al., 1996; Vaitillingom & Liennard, 1997; Zamora et al., 1997; Gubitz et al., 1999; Augustus et al., 2002; Kumar et al., 2003; Pramanik, 2003; Akintayo, 2004; Forson et al., 2004; Kpoviessi et al., 2004; Chitra et al., 2005; Adebowale & Adedire, 2006; Reddy & Ramesh, 2006.

The economics of biodiesel refinement varies across scales of production and is largely dependent on the capacity of the processing unit and the cost of transporting sufficient raw material to achieve capacity. Relationships between the annual capacity of the refinery and respective costs per unit of biodiesel produced are discussed in Chapter 3 (section 3.2.2). Another important determinant of processing cost is the type of facility that is installed, either a batch or a continuous flow unit. Continuous flow processing is designed to recover as much methanol and catalyst as possible, recycling these into the next reaction with feedstock continuously. Batch processing refers to discrete processing runs which are inherently less efficient from the point of view of maximizing the use of raw material and other inputs (Adriaans, 2006). The major criteria in selecting an appropriate type of processing unit, from an economic perspective, are case-specific and largely dependent on the scale of feedstock production and the capital investment cost (Adriaans, 2006).

2.3.3. Oil Extraction

The first step in processing feedstock after it has been cultivated is to expel the oil from seed kernels. Hence, the requirements for this stage are *Jatropha* seeds and mainly infrastructure and energy. This can be achieved cheaply, but at a low efficiency, or very high in working capital, at an almost perfect efficiency in regards to the total amount of oil recovered. Extraction can be done mechanically or chemically, from the most uncomplicated and ancient techniques to the highly dangerous and technologically advanced.

After removing the husk of the fruit to obtain the seeds, before oil extraction can take place, it is common practice to dry the seeds (Henning, 2000; Tobin & Fulford, 2005). Whole seeds can be fed into mechanical presses and need no further manipulation. For chemical extraction the kernel needs to be removed from its shell which can be used as another by-product which is easily combustible. Kernels are usually partially crushed before being added to a chemical solvent for oil extraction.

Mechanical Pressing

Mechanical presses can be operated manually or motorized. Manual presses, such as the Bielenberg ram press, apply the mechanical force through a lever operated by a labourer. Motorized presses, such as the Sundhara press (Henning, 1995), generate the mechanical force through a screw-mechanism powered by an engine. The efficiency of these devices is measured by the amount of extractable oil that is expelled (Table 2.3). Motorized mechanisms achieve a higher yield than manually powered presses, the efficiencies range between 70 – 80 % for the former, and 60 – 65 % for the latter (Henning, 2000; Forson *et al*., 2004; Rabé *et al*., 2005; Beerens, 2007; Tewari, 2007). A wider range of efficiencies is observed using motorized presses, even a yield as high as 90 % of the oil mass can be achieved by increasing the number of iterations of pressing and by pre-cooking the seeds (Beerens, 2007).

Solvent Extraction

Solvent extraction plants run at higher costs than those involved in mechanical pressing. Adriaans (2006) suggests that this cost is roughly double that of expelling oil mechanically and only becomes feasible at a minimum factory capacity of 50 tonnes of biodiesel per day. The most conventional solvent commercially used is *n*-hexane which achieves the highest oil yield at present. Extraction using *n*-hexane requires adequate safety precaution as this solvent is inflammable and fumes are hazardous to human health. It has potential environmental impacts; *n*-hexane extraction requires steam which results in higher energy consumption than mechanical extraction, produces waste water which needs disposal and also emits volatile organic compounds. Alternative technologies are available which are promising from the perspectives of environmental impacts and human safety, these include; aqueous enzymatic extraction (Winkler *et al*., 1997; Shah *et al*., 2005), using ethanol and isopropyl alcohol as solvents (Hui, 1996), and the use of supercritical CO_2 to break down cell walls to access seed oil (Willems, 2007). However, aqueous oil extraction solvents do not recover as much oil as *n*-hexane. Ethanol or isopropanol, although attractive as they are bio-renewable, and supercritical CO_2, which may have the least environmental impact of them all, are technologies which need further research before they become commercially viable alternatives to *n*-hexane extraction.

Table 2.3: Oil recovery from different extraction techniques

Extraction Method		Yield (%)	*Ref.*
Mechanical			
motorized screw press		68	*[1]*
		80	*[2]*
		79	*[3]*
ram press		62.5	*[4]*
		62.5	*[2]*
Chemical			
n-hexane (Soxhelt apparatus)			*[4],[5],[6]*
	1st acetone 2nd *n*-hexane	95 - 99	*[7]*
aqueous oil extraction (AOE)		38	*[8]*
		38	*[9]*
	AOE with 10 mins of ultrasonication as pretreatment	67	*[9]*
aqueous enzymatic oil extraction (AEOE)			
	hemicellulase or cellulase	73	*[8]*
	alkaline protease	86	*[8]*
		64	*[9]*
	alkaline protease with 5 mins ultrasonication pretreatment	74	*[9]*
three phase partitioning		97	*[10]*

Taken from Achten et al. (2008), sources: [1] – Rabé et al., 2005; [2] – Tewari, 2007; [3] – Beerens, 2007; [4] – Forson et al., 2004; [5] – Gubitz et al., 1999; [6] – Heller, 1996; [7] – Augustus et al., 2002; [8] – Winkler et al., 1997; [9] – Shah et al., 2005; [10] – Shah et al., 2004.

Jatropha Seedcake

The product from the extraction process step is *Jatropha* oil, but perhaps almost equally important is seedcake as a by-product. Oil seed meals, such as that obtained from soya, prove to be a critical component in the economic feasibility of biodiesel produced from edible oil seeds (Taheripour *et al*., 2010). Edible oil seeds can deliver high protein seedcake used as cattle fodder, *Jatropha* seedcake; however, contains various toxins which make this by-product unsuitable as animal feed. Many *Jatropha*-biodiesel producing companies' research and development portfolios are looking for cost-effective means to detoxify seedcake for use as fodder. The toxins, predominantly phorbol esters, are biodegradable and decompose completely within 6 days (Rug *et al*., 1997). This creates the opportunity for *Jatropha* seedcake to be used as an organic fertilizer. *Jatropha* seedcake has a nutritional value higher than that of chicken and cattle manures (Francis *et al*., 2005).

Although these nutrients are not immediately soluble, as they are when in a mineral form, *Jatropha* seedcake has the potential to ameliorate soil nutrients; however, the actual decomposition rates are unknown. Additional advantages of using organic matter, such as *Jatropha* seedcake, as mulch and as a soil additive, are that it improves soil structure and cation retention, and it reduces soil-water evaporation (Schnitzer & Khan, 1978). Simultaneously, *Jatropha* seedcake acts as a biocide against insects, molluscs, fungi and nematodes (Shanker & Dhyani, 2006), which in summation makes it an attractive option over mineral fertilizers with equivalent nutrient compositions.

Jatropha seedcake can also be used as an energy source having a mean energy content of 18.2 MJ kg^{-1} (Aderibigbe *et al*., 1997; Gubitz *et al*., 1999; Openshaw, 2000; Augustus *et al*., 2002). Depending on the efficiency of oil extraction, the calorific value of *Jatropha* seedcake will vary with the amount of residual oil after extraction. Compressed *Jatropha* seedcake briquettes have been proposed as a means of household energy production (FACT Foundation, 2009). *Jatropha* seedcake, along with other *Jatropha* waste and litter, can also be anaerobically digested to produce biogas (Lopez *et al*., 1997; Staubmann *et al*., 1997;

Radhakrishna, 2007) as a fossil substitute in cooking, before it is used as a soil nutrient ameliorant.

Whether or not a market is created for the various *Jatropha* by-products, recycling seedcake, along with waste products, such as the husks of the fruit, the shells of the seeds, prunings and litter, can displace costs in cultivation (Achten *et al*., 2008).

2.3.4. Cultivating *Jatropha*

Feedstock production is the primary stage in the biodiesel production chain. Key factors in the efficiency of *Jatropha* seed production are the plantation site and preparation, the establishment of mature trees and the management thereafter, including the marketing of the product and linking to ex-situ production processes. As mentioned previously, the *Jatropha*-biodiesel industry is a relatively inexperienced one and variables influencing the quality of end-product are the genetic variability of the species and the environment in which *Jatropha* is propagated. This makes it quite difficult to generalize on cultivation as current practices are inconsistent. Despite showing a wide range of environmental tolerance in survival, best agronomic practice for achieving optimal land-use is not established.

<u>Site Requirements of *Jatropha*</u>

Maes *et al*. (2009a) define the climatic growing conditions of areas within *Jatropha*'s natural distribution by coupling the locality of herbarium specimens with corresponding meteorological data. *Jatropha* is distributed tropically and sub-tropically, in both warm moist regions and the drier latitudes with most of the specimens (87 %) studied by Maes *et al*. (2009a) having been discovered in tropical savanna and in monsoon climates. In contrast to popular expectation, *Jatropha* does not appear to be all that successful in lower rainfall climates, with less than 3 % of all the herbarium specimens having been discovered in a semi-arid or arid environment (Maes *et al*., 2009a). Actually, 95 % of those specimens included in that study (Maes *et al*., 2009a) grew in areas with a mean annual rainfall above 944 mm.

Jatropha distribution occurs naturally in tropical climates experiencing a lengthy dry season where evapotranspiration rates exceed precipitation for up to 7 months of the year (Maes *et al*., 2009a). Trees are well adapted to survive dry periods as they drop their leaves at the onset of the dry season and are stem-succulent (Maes *et al*., 2009a). Based on Table 2.4 optimal precipitation is most likely above 900 mm yr^{-1} and mean temperatures should neither drop too far below 20 °C nor exceed 28 °C. Areas which experience frost are not ideal. Perhaps for this reason, despite a lack of strong evidence, *Jatropha* does not grow at altitudes higher than 1800 m above mean sea level. Productivity favours soils which are sandier in texture; well drained with good aeration, and not necessarily nutrient rich. Heavier soils with greater clay contents may be higher in nutrient levels but may hamper the formation of roots and are inherently prone to water-logging. *Jatropha* cannot be cultivated on soils of this nature, particularly not vertisols, or similarly dense soils. The surface slope should not exceed 30°.

Table 2.4: Climatic growing conditions for *Jatropha;* author and parameters

		Gush, 2004	Hallowes, 2007	cited in Achten *et al*., 2008	inferred from Achten *et al*., 2010
Altitude	m (AMSL)	0 - 1600	0 - 1700	0 - 1800 [1]	
Annual Precipitation	mm				
unsuitable		< 250	< 300	< 250 or > 3000 [1]	
marginal		250 - 500	300 - 600		< 944 or > 3121
suitable		500 - 900	600 - 900		944 - 1207 or 2001 - 3121
optimal		900 - 1200	900 - 1200		1207 - 2001
Mean Temp.	°C				
unsuitable			< 11 or > 38		< 11 or > 36
marginal			11 - 15		11 - 19 or 27 - 36
suitable		11 - 20	15 - 38		19 - 27
optimal		20 - 28	20 - 28	20 - 28 [2; 3]	23 - 26
Soil Character.					
unsuitable		water-logged		vertisols/clays prone to water logging [4; 5]; pH > 9 [5; 6]	
marginal		prone to water logging		heavy soils hamper root formation [2]	
suitable		low in nutrients			
optimal		well drained and aerated		at least 45cm deep [7]; sandy, well drained and aerated [1; 2]	
Frost	days (consecutive)				
unsuitable			> 120 (> 60)		
marginal			90 - 120 (30 - 60)		
suitable			0 - 90 (0 - 30)		
optimal			0	0 [2; 7]	
Surface Slope	degrees				
unsuitable			> 15	>30 [6]	
marginal		0 - 3 or 15 - 30			
suitable		3 - 15	10 - 15		
optimal		3 - 10	3 - 10		

Sources cited in Achten et al. (2008): [1] – Foidl et al., 1996; [2] – Heller, 1996; [3] – Makkar et al., 1997; [4] – Singh et al., 2006; [5] – Biswas et al., 2006; [6] – Tewari, 2007; [7] – Gour, 2006.

Jatropha Establishment and Maintenance

Vegetative propagation is common practice with high establishment success (Heller, 1996; Henning, 2000; Openshaw, 2000). It is easy to establish trees from cuttings from mature trees; however, these do not develop a taproot but a fine network of shallow roots. This has implications for the tree's ability to access water. In sandy soil, which is a feature preferential in site selection, water infiltrates with relative ease, hence a deep rooting system is advantageous and reduces the risk of uprooting in strong winds (Soares Severino *et al*., 2007). It is recommended for oil production purposes in monoculture plantations, agroforestry and intercropping systems, that *Jatropha* be grown from either direct seeding or nursery pre-cultivated seedlings (Jongschaap *et al*., 2007). The presence of a taproot will aid trees in accessing water and dissolved nutrients deeper in the soil and avoid competition with intercropped species (Heller, 1996). Generative propagation has its advantages; however, for rapid propagation the 'cuttings' method is preferred (Heller, 1996) and often in hedgerow plantations. Hedgerows are widely cultivated in India on wastelands such as levees, dykes, railway and road sidings and field perimeters.

Experience with successful vegetative propagation varies, with recommendations of cutting length (Henning, 2000; Gour, 2006; Kaushik & Kumar, 2006), diameter (Kaushik & Kumar, 2006), age (Gour, 2006), and origin of source (Kaushik & Kumar, 2006); either upper, middle or lower from parent canopy, being prominent factors. Timing of planting is also a significant feature, recommended during the rainy season (Gosh & Singh, 2007).

Timing of the sowing of seeds or seedling planting is also discussed as an important factor in *Jatropha* survival. It is recommended that direct seed sowing occur at the beginning of the rainy season, after the first rains when the soil is moist, to benefit taproot growth (Gour, 2006). For nursery pre-cultivation, seeds should be sown three months before the onset of the rainy season (Henning, 2000) so that seedlings can be planted in the field after the first rains, or at least in the warm season if irrigation can be supplied (Openshaw, 2000). Gour (2006) recommends that seedlings are watered frequently during the first 2 - 3 months after planting, depending on the frequency and volume of rainfall naturally. Nursery seedlings should be cultivated in polythene bags with a mixture of sandy loam soils and compost with high organic matter contents, in the ratio of 1:1 (Kaushik & Kumar, 2006), and well watered (Henning, 2000). Germination can be enhanced by soaking seeds in a slurry of cattle manure for 12 hours or in cold water for 24 hours (Achten *et al*., 2008). Germination success can be as high as 96 % for the former pretreatment and 72 % for the latter. Hot water and acidic solutions are ineffective pretreatments for improving germination (Brahmam, 2007).

Land clearing is important for establishment and although ploughing is a possibility, it may not be necessary, nor does the success of establishment necessitate the clearing of all above ground vegetation (Gour, 2006). However, the presence of a grassy sward inhibits the growth of *Jatropha* trees (pers. obs.). It is recommended that the herbaceous component be removed to give *Jatropha* a competitive advantage during establishment and if desired, existing trees can be spared (Gour, 2006). After clearing, the land needs further preparation by digging pits for planting before the rainy season; 30 x 30 x 30 cm^3 – 45 x 45 x 45 cm^3 (Gour, 2006; Singh *et al*., 2006), so that seedlings can be planted after the first rains and pits refilled with a mixture of soil, sand, manure/compost and mineral fertilizer.

Typical crop spacing is 2 x 2 m up to 3 x 3 m (from 1111 – 2500 trees ha^{-1}). Wider spacing patterns are characteristic of silviculture or agroforestry, such as 4 x 3 m and as much as 6 x 6 m (Kaushik & Kumar, 2006) depending on the interspersed crop. Crop spacing patterns correlate to both seed yield per individual and per hectare, in trade-off to each other. Narrow crop spacing results in higher seed yields per hectare, but lower individual tree yields, whereas, more sparse spacing improves individual seed yields but decreasing per hectare yield (Chikara *et al*., 2007). An optimum must be sought but this is a product of the characteristics of the site, being fertile and supportive of individual tree productivity or low in fertility, where optimization may be met by increasing the number of trees per hectare to account for poorer individual performance. More research is needed to affirm this assumption.

A personal observation is that maturing *Jatropha* trees do not perform well when encroached upon by vegetation and that there is little opportunity for natural propagation if there is herbaceous ground cover to compete with. More outdated handbooks and reports on *Jatropha* management infer that *Jatropha* is a hardy species which requires very little maintenance (Jones & Miller, 1992; Heller, 1996; Henning, 1996; Openshaw, 2000), but most of those; however, do mention that weeding is in fact a necessity. More recently, publications outline more stringent guidelines for maintaining the crop (Euler & Gorriz, 2004; Gour, 2006; Kaushik & Kumar, 2006; Singh *et al*., 2006; Tigere *et al*., 2006). Weeding is essential and although *Jatropha* may be a hardy species, simply surviving does not make this crop commercially viable. The litter and weeds removed can be used as mulch which reduce rates of soil evaporation and can slowly contribute to soil organic matter. Inputs will be met with improvement, optimizing levels of input and quantifying responses to inputs are areas where significant research needs to be targeted.

Fertilization and irrigation initiate productivity but whether or not those inputs result in biomass production or increased seed and oil yield remains uncertain. Gush (2008) estimates the water-use efficiency of both 4 year old and 12 year old *Jatropha* trees and concludes that, based on the trees sampled, *Jatropha* is conservative in its water-use and is not likely to transpire greater volumes of water than indigenous flora of the region. Quantitative data for water-use and *Jatropha* water requirements provided in the literature (Gush, 2008; Gerbens-Leenes *et al*., 2009a; Gerbens-Leenes *et al*., 2009b; Jongschaap *et al*., 2009; Maes *et al*., 2009b) are not in agreement, nor are reliable estimates for the yield response to irrigation. Fertilizer is reported to increase yield but insufficient data are available to make reliable estimates for how efficiently fertilizer can be applied to *Jatropha* plantations. Optimum levels are expected to vary with the age of trees (Patolia *et al*., 2007) and in one case it is observed that organic matter induces a greater response than mineral fertilizer (Francis *et al*., 2005). Harvesting results in significant nutrient losses to the system. Seeds are comprised of, on average; 1.4 – 3.4 % nitrogen (N), 0.07 – 0.7 % phosphorus (P) and 1.4 – 3.2 % potassium (K) (Jongschaap *et al*., 2007), hence, each tonne of seed harvested removes 14 – 34 kg N, 0.7 – 7 kg P and 14 – 32 kg K. The required fertilizer input is dependent on the initial fertility of the soil; however, to prevent excessive mining of nutrients from the system, the annual fertilizer requirement can be assumed to equal that of the mass of nutrients removed during harvesting (Jongschaap *et al*., 2007).

Continuing with the trend of a vast underestimation of the maintenance requirements of *Jatropha*, it is popular belief that *Jatropha* is not prone to pests. Several pests of *Jatropha* have already been identified and the economic impact is noticeable in monocultures in India (Shanker & Dhyani, 2006) and Mozambique (JA & UNAC, 2009). Fertilization and irrigation may further stimulate insect infestation and disease (Sharma, 2007), resulting in increased economic losses to monoculture plantations. Accordingly, pesticide use may need to increase proportionally to the application of fertilizer and irrigation. This again highlights the importance of understanding the feedback of inputs on yields as fertilizer, irrigation, pesticides and herbicides may result in significant costs to the production stage of the feedstock. Feedstock sales need to, in addition to labour costs and overheads, support the maintenance costs of the plantation to be economically feasible.

Pruning has been identified as a very important maintenance practice for improving yields (Gour, 2006). It is recommended that the tree is pruned at a height of 30 – 45 cm (Gour, 2006) on the primary shoot at the age of 6 months, depending on the growth rate. Removing the terminal node encourages lateral branching (Gour, 2006; Kaushik & Kumar, 2006). Further pruning of the tertiary branches induces more branching, which is believed to gradually increase the number of inflorescences and consequently the eventual abundance of fruit (Gour, 2006).

Manipulating canopy architecture also helps maintain the tree at a manageable height for harvesting and increasing the number of lateral branches further aids picking rates. At present manual harvesting is the reality; however, a mechanical dehusker was tested in

Honduras over an 8 month period, commencing in August 2009, on a 550 ha *Jatropha* plantation (Biofuels Digest, 2010; BEI International, accessed 28/07/2010). The BEI *Jatropha* Wave Harvester in operation can be viewed online (http://www.youtube.com/watch?v=D5oaeTRZpOo, accessed 07/07/2010). It is evident from the video that the harvester is effective in removing fruit; however, an issue that may continue to undermine the viability of mechanical harvesting is the ability to select mature fruit, discriminating against fruit that is not ready for picking. The BEI *Jatropha* Wave Harvester is not entirely successful in doing so. Synchrony of *Jatropha* flowering and fruiting does not exist but evidence remains to be seen as to whether or not the appropriate phenology of reproductive growth can be manipulated by irrigation and/or the use of growth regulators to aid in harvesting. This could have significant ramifications for the labour cost of *Jatropha* production. Best oil yields are achieved from picking mature fruits, yellow-brown in colour (Achten *et al*., 2008). This makes harvesting highly labour intensive as it needs to be selective and repeated regularly (Heller, 1996; Singh *et al*., 2006). The length of the harvesting period varies according to the climatic conditions of the site (Kaushik, 2006). Longer wet seasons support longer periods of fruiting and require harvesting continuously. Yields in semi-arid climates may only require regular harvesting seasonally.

In the rural context, labour availability will often be constrained by the labour demand of subsistence agriculture. Competition for household and community labour may prove to be the strongest inhibiting factor for the establishment of *Jatropha* plantations. Whilst harvesting will certainly be a significant demand for available labour, tree establishment requires a great deal of labour and planting coincides with the preparation of agricultural fields ahead of the rainy season. More site-specific investigation should be considered. More site-specific investigation should be considered.

Jatropha Seed Yields

Perhaps the most significant risk to the financial viability of *Jatropha* growing is not the underestimation of the management cost of production but the overestimation of potential yields. Making a reliable estimate of mature seed yields is not possible based on reports in the literature as most commercial plantations are still in an early stage. Reported yields are highly variable, ranging from 0.3 to over 12 t ha^{-1} yr^{-1}. The variance can be attributed to the age of trees (Heller, 1996; Sharma *et al*., 1997), geographical, climatic and soil gradients (Aker, 1997; Openshaw, 2000; Francis *et al*., 2005), management and maintenance of the plantation (i.e. crop establishment, crop spacing, fertilizer application and irrigation) (Heller, 1996; Gour, 2006; Singh *et al*., 2006), genetics (Ginwal *et al*., 2004), and whether reports are based on empirical evidence, are extrapolations from individual tree yields, or are simply not scientific at all.

During a *Jatropha* conference in Wageningen in March of 2007 experts agreed on an acceptable estimate of annual yields of 3 – 5 t ha^{-1} (EU, 2007). Heller (1996) and Tewari (2007) estimate that 2.3 t ha^{-1} yr^{-1} can be achieved on wastelands in semi-arid environments which is in agreement with data collected by Francis *et al*. (2005). Under more ideal conditions yields of 5 t ha^{-1} yr^{-1} and above are suggested (Larochas, 1948, cited in Hallowes, 2007; Behrens, 1994, cited in Hallowes, 2007; Foidl *et al*., 1996; Heller, 1996; Francis *et al*., 2005; van Eijk, 2006; Tewari, 2007). Figure 2.2 displays a select range of reports found in the literature.

Approximately 90 % of all reports in the literature (up to and including publications during 2008) are less than 5 t ha^{-1} yr^{-1}; 40 % between the experts range (EU, 2007) and 28 % below a yield of 1 t ha^{-1} yr^{-1}. Not shown in Figure 2.2, the lowest recorded yield is 100 kg ha^{-1} yr^{-1} for a three year old plantation in Paraguay (Matsuno *et al*., 1985) and the greatest is an estimate for Tanzania of 10 – 20 t ha^{-1} yr^{-1} extrapolated from individual tree yields of 4 – 8 kg (van Eijk, 2006). The mean yield from the entire dataset is 3432 kg ha^{-1} yr^{-1} (the standard deviation of which is 3793). The median is most definitely a far better description of the data considering the ‘skewness’ of the distribution, which is 2393 kg ha^{-1} yr^{-1}, outside the expert’s range of 3 – 5 t ha^{-1} yr^{-1} (EU, 2007). Excluding reports above 5 t ha^{-1} yr^{-1} the mean yield is 2 ±1.5 t ha^{-1} which is a little more plausible and it matches the median. Seventy-five percent of the selected range is below 3.5 t ha^{-1}, 50 % below 2 t ha^{-1} and the lower quartile is below a single tonne.

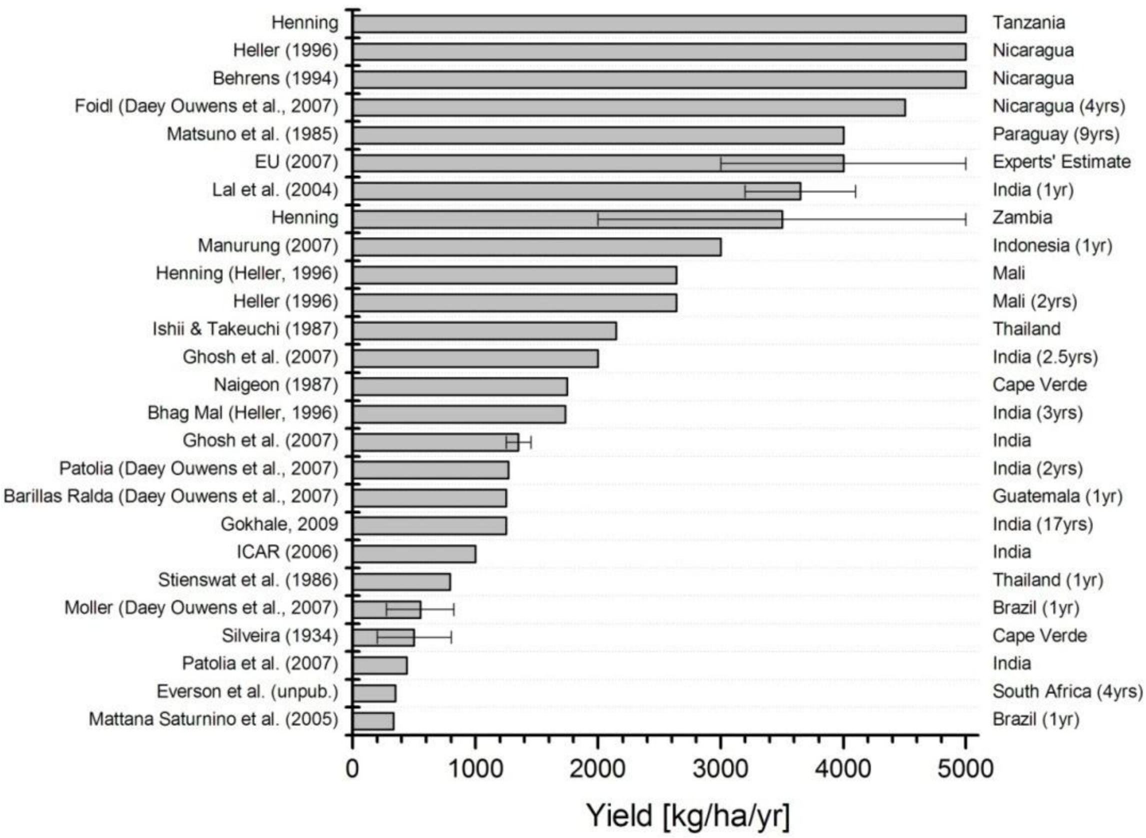

Figure 2.2: Jatropha yield; author and location. Selection of yield reports up to and including 5 t ha^{-1} yr^{-1}. Error bars denote the range in report given by the author for those which provided a range and not a mean. Values in brackets indicate the age of trees reported upon.

It must be acknowledged that even the most reliable data records are from plantations which have not reached the theorised age of maturity, so achievable yields may in fact be greater than 3 t ha^{-1} yr^{-1}. Data from the most mature plantations are bimodal. Patil (cited in Gokhale, 2009) records a yield of 1250 kg ha^{-1} after 17 years of growth in India whereas Matsuno *et al*. (1985) record 4000 kg ha^{-1} in the Paraguayan plantation's ninth year. It can be concluded that site characteristics and management will play a critical role in the yield of *Jatropha* plantations, and claims that *Jatropha* is high yielding under marginal conditions and low inputs are completely inaccurate.

2.4. Characterizing Projects and *Jatropha* Farming Models

Recently the first comprehensive market study for *Jatropha* was conducted (GEXSI, 2008a), identifying 242 projects globally, spanning roughly 900,000 ha, of which 85 % has been cultivated in Asia. Regions making significant investment are Asia, Africa and Latin America, with 104, 97 and 41 projects identified in those respective regions (GEXSI, 2008a). India, with 400,000 ha planted (GEXSI, 2008a), was one of the first countries to commit to growing *Jatropha*, and has one of the largest areas planted. Important African players are Ghana, Madagascar, Mozambique, Zambia and Tanzania whilst Brazil has the greatest area planted to *Jatropha* in its region of the world (GEXSI, 2008a).

Two-thirds of all projects analysed in the GEXSI study (2008a) work with local small-growers, often in combination with managed plantations; fifty percent of the projects in Asia opted for this approach and 66 % in Africa, and production for local markets is more important than export, especially in Asia. Southern Africa and India have been targeted for *Jatropha* production, based on a wide range of socio-economic and environmental conditions. *Jatropha* plantations in these regions can be characterized according to their scale of production and the markets they target (von Maltitz & Setzkorn, submitted). Despite having a high diversity in the scale of production and types of biofuel business, investment and management models applied, projects can be generalized by either endeavouring to improve fuel security locally, or by attempting to supply international and domestic transport-fuel markets (von Maltitz & Setzkorn, submitted).

The types of biofuel projects of interest to this study are those specifically aimed at supporting national and international liquid-fuel blends. These projects are incentivised by cash for crop and not by local fuel security (von Maltitz *et al*., 2009; von Maltitz & Setzkorn, submitted). The biofuel industry provides support and inputs, financing, technological assistance as well as a market (von Maltitz *et al*., 2009). Arguably, biofuels are an attractive farming option on account of the assistance received by the farmers (Haywood *et al*., 2008) in addition to the intrinsic value of the biofuel crop itself. A number of farming models are currently being used and tested in India, which have been discussed by Harrison *et al*. (submitted), and in sub-Saharan Africa by von Maltitz and Setzkorn (submitted).

2.4.1. The Indian Farming Model

In India, trees have been planted on communal land, usually with the involvement of non-governmental organisations, using public works type programmes and the fruits are available as a non-timber forest product for villagers to pick. A minimum price of INR 4.00 – 6.50 (~ 9 – 14 US cents) is guaranteed to the pickers for a kilogram of seed, though the actual price received tends to be higher, and as much as INR 14.00 (~ 30 US cents) on the open market. In addition, a number of companies are assisting small-scale farmers to grow *Jatropha* on a portion of their privately owned land, sometimes under a contract scheme, for purchasing the seeds they produce. These companies are typically biofuel producers and are hampered by the lack of feedstock and are attempting to stimulate the market. This “contract” farming model varies between companies and in some instances involves the farmers entering into long term agreements of up to 30 years and financial capital loans of up to INR 8,000 (~ US$ 175) per hectare.

Other companies are providing the capital required to start production and provide technical support as well. In these cases labour is not formally employed and opportunity costs are kept to a minimum whereas certain contract agreements outline strict management requirements, and additional labour may likely be needed.

The Indian Oil Corporation (IOC) is entering into joint ventures with state governments to establish and manage plantations on government land, where rural employment is offered. The IOC are contracted by the Indian Government to produce and procure, process and distribute fuels to retail outlets but are faced with a relatively unique challenge. The Indian Government sets the retail price for transport fuels which leaves the IOC at the mercy of the prevailing crude oil price. When the cost of procuring feedstock is high the IOC runs at a net loss per litre of fuel sold to the consumer. This system does not guarantee that the IOC will recover all the costs involved in purchasing, refining and distributing fuel, therefore the IOC wishes to explore the opportunity of producing alternate fuels at a lower cost than what they can purchase crude oil for. The IOC's participation in these joint ventures for growing *Jatropha* is motivated by profits, the Indian Government sees these as an opportunity for rural development.

2.4.2. The Sub-Saharan Africa Model

In Africa, land tenure plays a significant role in determining the types of farming models implemented. Land tenure in Africa is complicated but can generally be classified as either statutory or customary; covering a suite of customary ownership, land-use rights and post colonial land redistribution. Large-scale commercial farming is usually undertaken on land in private statutory tenure but, in Mozambique and Lesotho for example, all land is state owned and biofuel corporations can only acquire land for feedstock production on long-term lease agreements. Forests, rangelands and wetlands make up 40 % of the sub-Saharan African landmass (Alden (2005) cited in von Maltitz and Setzkorn, submitted), the majority of which is under some type of collective customary ownership. Customary tenure does not infer individual land entitlement. Biofuel companies have been accused of disenfranchising social groups by procuring their land based on deals negotiated between the developer and the customary leaders who are the local authority.

Biomass is an important energy resource in sub-Saharan Africa and the lack of infrastructure in many countries delivers inherently poor supplies of electricity, which is a contributor to poverty. As in India, many NGO's see the potential in biofuels for rural development as a solution. A considerable number of these see the end-use for the biofuel product being local consumption, contributing to fuel security. Fourteen out of the 40 countries in Sub-Saharan Africa are landlocked, leading to high delivery costs for fuels, on average 50 % higher than the cost at coastal regions (von Maltitz *et al*., 2009). Many of the developments which target the feedstock market for international and regional fuel-blending are large scale and usually funded by overseas investors. These corporate-type models are usually in the scale of 1000's to 10,000's of hectares.

A higher proportion of these projects are linked entirely to outgrowers. Two models dominate at the outgrower scale; one which involves cooperatives of technical support and the cooperative sells feedstock to the producer, the other being a contract agreement between the farmer or several small-scale farmers and the biofuel producer, who directly provides assistance in plantation establishment. Also, in Zambia for example, D1 Oil Ltd. aims to set up larger contiguous blocks of *Jatropha* plantation. These may be medium sized, a few hundred hectares, privately owned farms under statutory tenure or a concession of many small-scale farms in customary land tenure. However, to the best of von Maltitz & Setzkorn's knowledge (submitted), none exist at present.

Outgrowers may see growing biofuel feedstock as complimentary to their current land-use or subsistence livelihood because these farmers receive technical assistance and some crucial inputs to feedstock production, such as fertilizer. The support provided by the biofuel producer can therefore increase the net agricultural output, particularly in intercropping systems.

2.5. Future Considerations for *Jatropha* Cultivation and for Biofuel Policy

Considerable political weight has been applied towards targeting *Jatropha*-biodiesel for commercial use in the transport sector. Economic development is addressed by objectives for large-scale centralized biodiesel refinement for either regional consumption or for export to international markets for meeting mandatory fuel blends. As a mechanism for rural development, by improving local fuel security and stimulating trade at a micro-economic scale, these potentials have largely been overlooked as secondary benefits.

The economic viability of *Jatropha* production is still highly uncertain. Extrapolating from experience at a small-scale to large-scale commercial operations is unwise and unrealistic. Regardless, the global hype surrounding *Jatropha* as a biodiesel feedstock has sparked developments in many regions of the world, particularly in those that are sub-tropical and under-developed. However, experience of lower than expected yields and stronger appreciation for the relative cost of production, together with competition on the rapidly growing international biofuels market, is shaping new perspectives for *Jatropha* as a biodiesel feedstock (Achten *et al*., 2010). Avoiding risk of low yields and financial losses, investors may be forced to target less marginal sites and compete with other markets for access to fertile lands. This has implications for the validity of *Jatropha*-biodiesel's widespread sustainability acclaim (Achten *et al*., 2010).

Achten *et al*. (2010) suggest an opportunistic approach to the global hype by integrating small-scale farmers into community-based *Jatropha* cultivation initiatives through small plantations, *Jatropha* intercropping and agro-silvo-pastoral systems, and by exploiting the entire *Jatropha* value-chain. *Jatropha* oil is easy to extract (Achten *et al*., 2008) at low cost (Messemaker, 2008) and can be used to augment poor and/or expensive supplies of petroleum-fuels. Furthermore there are various useful applications of other *Jatropha* products, such as biomass and litter for fermentation, seedcake for fertilization or combustion (Gubitz *et al*., 1999), seed husks and kernel shells for heat generation (Gubitz *et al*., 1999), and the use of hedges for excluding livestock and protecting food crops (Gubitz *et al*., 1999; Zahawi, 2005).

Multipurpose *Jatropha* production systems are not the focus of this research which aims to contribute to a better understanding of the economic sustainability of *Jatropha*-based initiatives which specifically target the biodiesel market. However, in the context of the literature and for future considerations, all potential applications of *Jatropha* production should be explored. For one important reason; a major concern for economic development through biofuel feedstock expansion in developing countries is that the benefits may not be as great as expected due to international market competition, especially if feedstock is exported raw and processed closer to the consumer (Haywood *et al*. 2008; von Maltitz & Brent, 2008), namely Europe. Processed products from poorer nations, in contrast to raw materials, get vastly higher tariffs at richer nations' ports (Oxfam, accessed 28/07/2010). One significant advantage of the multipurpose approach is that it does not require an entire commitment to *Jatropha* production, not all land needs to be dedicated to feedstock cultivation, and the farmer is able to control what start-up capital is invested.

Chapter 3: Model Development

The following two chapters directly address the second objective outlined in Chapter 1, namely: to develop a model specifically for determining the maximum returns for labour at different wholesale prices, production costs and yield scenarios. As a preamble to this chapter, Chapter 4 is formatted as a manuscript to the study to facilitate the publication thereof, and is included in the dissertation, but for the purpose of comprehensively describing the model development, capabilities and application this chapter has been included. Chapter 3 briefly describes the theoretical framework of the model and is then formatted to outline the *Jatropha*-biodiesel production chain as it is internalized in the model. Specific parameterization of the model is given in Chapter 4; however, there may be some repetition between the two chapters.

3.1. Theory

Whilst seemingly having the potential to contribute greatly to rural employment, significant labour costs may undermine the profitability of *Jatropha*. For *Jatropha* cultivation to improve rural livelihoods, the biodiesel production chain needs to be profitable enough to support an income for labour that is both economically sustainable and poverty reducing. As a minimum requirement, in commercial plantations where labour is employed, the legal minimum wage needs to be supported. For independent pickers and small-scale farmers, income must exceed the opportunity costs of labour. The maximum wage for labour is governed by the production efficiency of the chosen feedstock and the price at which biofuel can be sold. Since liquid biofuels directly replace fossil fuels the value is effectively set by the prevailing price of the petroleum product, unless distorted by differential taxation or subsidy (Tyner, 2008).

A spreadsheet based financial model was developed from life-cycle economic analysis of the *Jatropha*-biodiesel production chain. The main assumption of the model is that the biodiesel sales price is proportional to the prevailing petro-diesel price. Therefore, *Jatropha*-biodiesel production should be more profitable where petro-diesel prices are high. The legal minimum wage will also have significant ramifications for production labour costs, and as a consequence, the economic sustainability of biodiesel production at a given fuel price. The ideal environment for feedstock production should, in theory, be in regions that experience high fuel prices and tolerate low labour wages. This depends greatly on the efficiency of *Jatropha* production and the choices made by management.

3.2. Structure of the Model

The model traces the *Jatropha*-biodiesel production chain which has been discussed in Chapter 2 (section 2.3). A top-down systematic approach is used to calculate, in series, the maximum price the refinery could charge for biodiesel (factory-gate price), the maximum price that can be offered to farmers for feedstock (farm-gate price), and finally, the maximum daily wage that can be paid for farm labour. This is essentially the core model which is linked to ancillary sub-models that account for other production and operating costs on the farm (Fig. 3.1). These sub-models can be switched on or off to investigate different management scenarios such as an overhead cost, the cost of fertilization, additional maintenance costs, establishment costs and the cost of compounded interest on capital loans. Sub-models can be populated with available data and run to generate usually a single output variable which is exported to the core model calculations or this output variable can be user-defined and not need the sub-model to run. The model is as intrinsically complex as need be but can also be run in its simplest form, as the core model, populated with a minimum number of user-defined variables; 4, in its simplest form, to 7, including a farm-overhead, -maintenance and -establishment cost. The benefits of this are that the model can be exhaustively populated for accuracy with case-specific data, if available, or using the most confident range in case-specific data to express a variety of possible scenarios. The model is already geared to provide an array of results based on different yield and fuel-price scenarios.

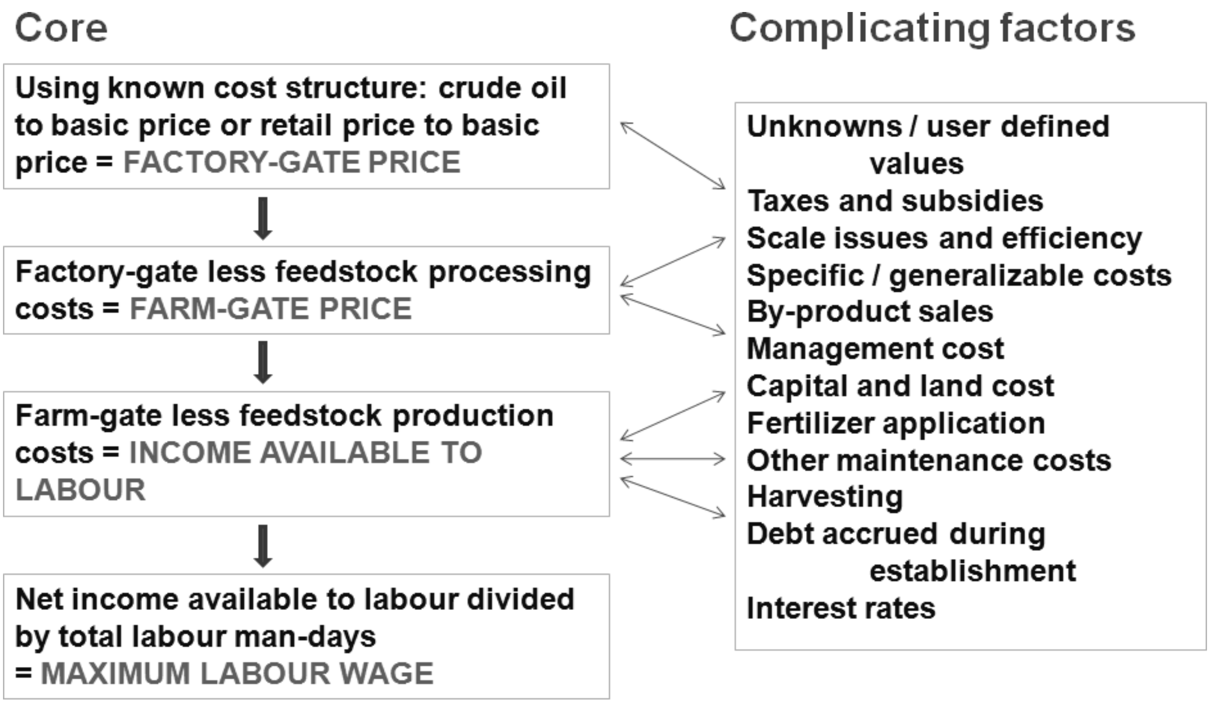

Figure 3.1: Conceptual flow chart of the model. Complicating factors, not necessarily as they appear in the list to the right in the figure, are distributed into independent and contiguous units or sub-models.

Different cost scenarios are illustrative of the type of farming model used, such as those described in Chapter 2 (section 2.4), be it scale-dependant and/or inherent of different management choices. Scale-characteristic traits of these farming models can be contrasted between, for example, small-scale outgrowers to large corporations, where family labour is used, and large-scale plantations of the biodiesel producers, where labour is formally employed. As mentioned in the previous chapter (section 2.4), characteristics of *Jatropha* plantations can be generalized according to their individual scale of production and by the markets which they target for the end-use of the product (von Maltitz & Setzkorn, submitted). Regardless of the delineation, the model allows for the user to contrast between two farming models. The option to run competing farming models parallel provides the user the ability to compare different scenarios and management choices, or to test the sensitivity of the system to different variables by parameterizing the farming models identically sans the specific variable under investigation. The model allows for sensitivity analysis based on factory costs, by-product sales, yields and feedstock management practices. The following sections have been formatted in a structure corresponding to the series of steps in the model.

3.2.1. Modelling the Factory-Gate Price

The main assumption of the model is that the maximum biodiesel factory-gate price is equivalent to the cost of purchasing and importing petroleum-feedstock from international markets. In South Africa this is known as the Basic Fuel Price (BFP). The BFP reflects the realistic cost of importing a litre of oil from international distilleries (DME, accessed online 25/04/2010). The BFP is a fair baseline estimate for the maximum wholesale biodiesel price. Although biofuels may in the future receive subsidies and/or rebates on certain taxes and levies (DME, 2007), distribution costs from the factory to the retailer are likely to be similar to that of petro-diesel, as would retail costs. Thus any higher wholesale value for biodiesel would result in decreased compensation to the product marketer and the service station owner, if the retail value is to remain competitive with petro-diesel.

The pump price for petro-diesel in South Africa is calculated from the BFP using a structure of absolute transport and delivery costs and margins. Zambian retail prices are determined through the Cost-Plus Pricing Model (CPM) (ERB, 2005) which takes into account all costs associated with the purchase of the petroleum-feedstock. The CPM ensures that all costs incurred in the procurement of petroleum-feedstock are recovered through sales of petroleum products. Therefore, in practice, an estimate for the maximum biodiesel factory-gate price can be calculated from prevailing or projected petro-diesel pump prices, using such known cost structures.

As an alternative, it is also possible to estimate future wholesale prices for biodiesel from speculated future oil prices. The difference between prevailing crude oil prices and local fuel prices is a sum of transport costs, specific margins and fuel taxes, such as those in South Africa and in Zambia. Although those may not be fixed or absolute costs, and may be subject to the rate of exchange between local currency and the United States Dollar (US$), the logic would be that these margins and taxes are in place to compensate for the cost of procuring the petroleum-feedstock and should increase linearly with crude oil prices. Therefore, after correcting for mean rates of exchange between local currency and the US$, a regression can be developed from plotting historical crude oil prices against complementary local fuel prices. A linear trend (R^2 = 0.99) between barrel crude oil prices and the South African BFP from 2003 – 2008 is displayed in Fig. 3.2.

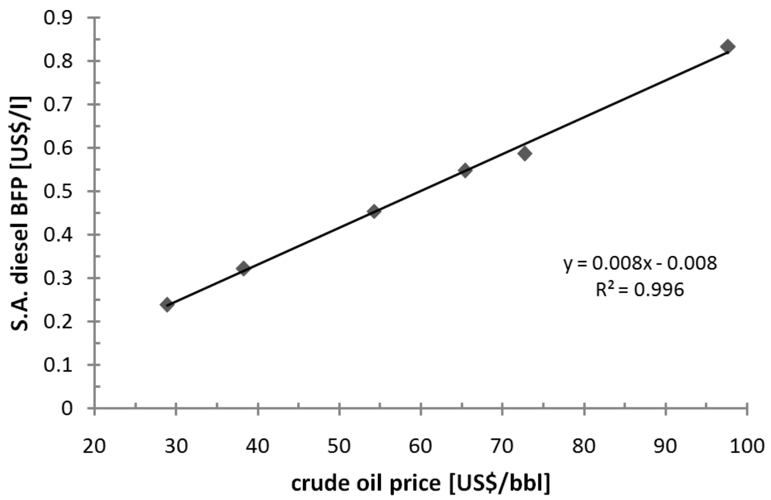

Figure 3.2: The trend between barrel (bbl) crude oil prices and South African BFPs from 2003-08. BFPs are corrected by mean annual US$ exchange rates. Sources: crude oil – World Bank Pink Sheets '03-'05, '06-'08, '07-'09; BFPs – DME.gov.za; US$ exchange rates – oanda.com.

Depending on what data are available, the user can simply input the BFP, choose to backward engineer an estimate from the pump price, or regress this value from the prevailing crude oil price.

3.2.2. Modelling the Farm-Gate Price

The maximum sales price for feedstock at the farm-gate is estimated by the factory-gate price less costs involved in refining and transport. The model allows for this cost to be based on raw cost structures, published regressions (Nguyen & Prince, 1996; Zhang *et al*., 2003b; Haas *et al*., 2006) or user defined values.

Factory Cost-Capacity Optimization

Significant factors affecting the location and size of a biodiesel refinery are the distance to the market and the productivity of the surrounding plantations. Transport costs are positively correlated to the scale of production, which is directly related to the intensity of the land-use. Varying the size of the factory has relatively limited impacts on the economics, except where very small-scale processing units are used. Figure 3.3 displays the relationship between various processing costs and factory-capacity.

Raw materials costs are related to factory capacity by economies of scale; the greater the quantity of raw materials purchased, the greater the discount in unit price. Maximization of this; however, is in trade-off to the scale of feedstock production necessary to realize capacity, hence the distance to transport raw material increases. Glycerine recovery should increase with factory size due to improved efficiency in larger factories; however, insufficient data were found to support this hypothesis and the credit of glycerine by-product per litre biodiesel produced has been fixed for all factory sizes (Fig. 3.3).

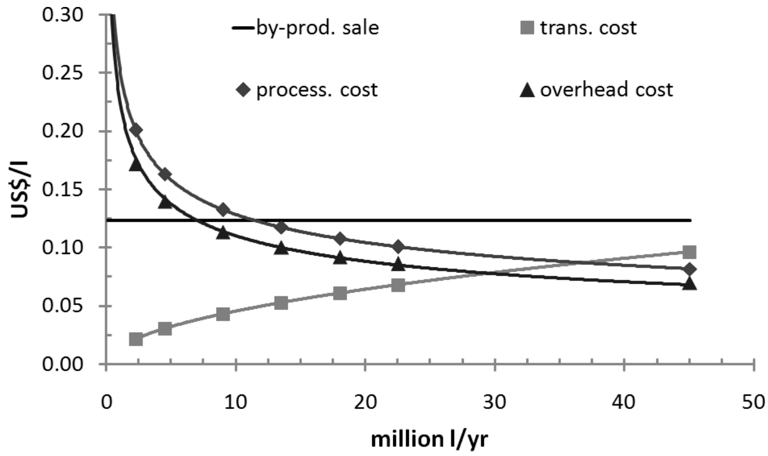

Figure 3.3: Factory cost-capacity regressions. Display the relative costs (US$) per litre of biodiesel produced at different annual processing capacities (million l yr^{-1}). Regressions are for (from left to right of the legend): glycerine by-product sales; transport costs; labour, utilities and raw materials costs (excl. feedstock); and overhead costs. Data from a South African case study, (Amigun, unpub.) adapted from Zhang et al., 2003b and using the Nguyen & Prince model (1996).

An important component affecting the farm-gate price is the value at which the by-products can be sold. The market for glycerine is known to be highly volatile even though it is used in many food and pharmaceutical products and in various manufacturing processes (Bender, 1999). With biodiesel production on the rise, the market could become saturated with glycerine supply, hence the demand will decrease and consequently so will its market value. Feasibility of biodiesel from soya is made possible by the relatively high value for seedcake as a protein-rich cattle fodder (Taheripour *et al*., 2010). *Jatropha* seedcake is toxic to animals and many *Jatropha* companies' research and development portfolios are searching for cost-effective means to detoxify seedcake for use as animal feed. *Jatropha* seedcake has a nutritional value making it applicable as an organic fertilizer, perhaps achieving a value equivalent to the fertilizer it replaces.

Once all refining costs and revenue from by-product sales have been estimated and the efficiency of esterification is accounted for, the maximum value for pure plant oil is known. Esterification efficiency is a measure of the mass of plant oil that will convert to either ethylor methyl-esters and is essentially expressed as the percentage yield, by mass, of biodiesel. The maximum value for plant oil is then converted to the maximum feedstock price by weighting for the inefficiency inherent in the oil expression process, hence the mass of feedstock required to manufacture a single litre of biodiesel and the residual funds available to purchase feedstock are known. The user can also simply input the net processing cost independent of factory size.

Oil Extraction Techniques

Broadly speaking there are two techniques of oil extraction applied; cold-pressing and solvent extraction, discussed in section 2.3.3 of Chapter 2. Cold-pressing uses a mechanical means for extracting the oil from seeds. There are multiple products available with different efficiencies inherent in the design. Efficiency is measured by the percentage of available oil that is extracted by the device. Two options are provided by the model; the use of either a ram press or a motorized screw press for extracting the oil. The efficiency of the former is less than the later, taken as 60 % and 80 % respectively.

As an alternative to cold pressing, solvent extraction can be selected. The option provided by the model is the use of the Soxhelt apparatus. The efficiency achieved using *n*-hexane is as great as 99 %. Adriaans (2006) suggests that this is only feasible at biodiesel production rates above 50 t day^{-1}. For this reason the model flags the choice of *n*-hexane extraction at annual factory capacities of less than 20 million litres per year.

3.2.3. Modelling the Maximum Farm Labour Wage

The maximum labour wage is calculated by the farm-gate price minus the farm production costs, divided by the total labour hours for production. Variables in feedstock production that lie within the core model are: calculating the net income available to labour; and estimating the labour required to harvest and dehusk seeds. Gross income is simply determined by multiplying the farm-gate price by the yields obtained. The number of labour man-days required during harvesting is determined by an estimate for picking rate which has been modelled against annual yields. Dehusking is either manual or semi-mechanical. The improvement in the rate of dehusking from manual to commercially available industrial products like the Universal Nut Sheller (Brandis, accessed online 15/01/2010) is three-fold.

Harvesting is labour intensive, but harvesting rates are poorly researched. Many reports define a maximum, or an average picking rate, irrespective of seed yields, and it is difficult to ascertain if these are estimates or based on experience or measurement. A synopsis of picking rates is provided in Chapter 3 of the FACT Foundation (2009) *Jatropha* Handbook, ranging between 2 and 10 kg hr^{-1}. By cross-referencing the location of these with complementary yield reports in the literature, and based on primary coupled data, of time taken to harvest yield on day of harvest, at a scientific trial at Ukalinga in Pietermaritzburg, South Africa (Everson *et al*., submitted); picking rate is related to yield by what was assumed to be a function of fruit density. Picking rate improves significantly with an increase in annual yield and subsequent fruiting density, slowing gradually as it approaches an asymptote. An exponential decay function was fitted to the data (R^2=0.95) to provide a tool for extrapolating picking rates from annual seed yields (Fig. 3.4).

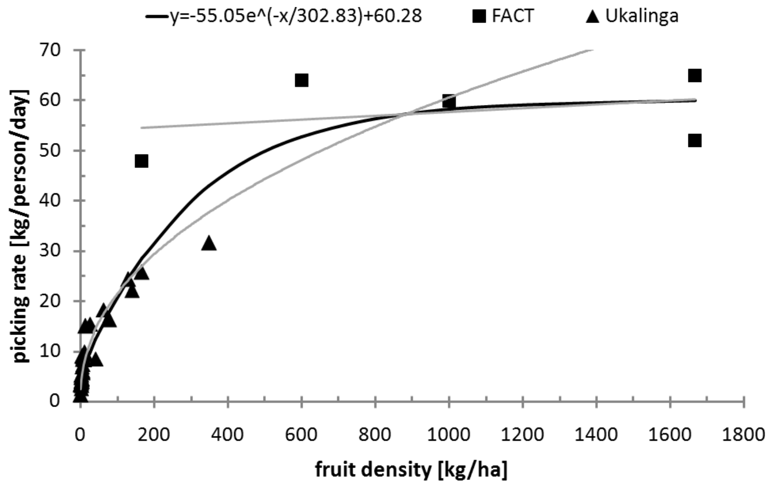

Figure 3.4: Rate of picking (seed) as a function of fruit density during harvest (measured as mean yield on day of harvest). Annual yield reports were divided by the assumed number of harvest events per year to interpolate the mean yield on day of harvest. Assumed number of harvest events per year was taken as 3. The grey lines are trends fitted to the FACT and Ukalinga data, respectively. Sources: FACT – picking rate: FACT Foundation, 2009; yield: Heller, 1996; Lal et al., 2004; Mattana Saturnino et al., 2005; ICAR, 2006; Daey Ouwens et al., 2007; Ghosh et al., 2007; Manurung, 2007; Patolia et al., 2007; Gokhale, 2009. Ukalinga – Everson et al., submitted.

By dividing the annual yield by the number of harvest events per year, divided by the picking rate at that fruiting density of harvest, provides the number of labour man-days required per hectare per year.

Accounting for Other Production Costs

The following variables that are discussed fall into ancillary sub-models to the core. As mentioned previously these are relevant to different scenarios and are case-specific. Chapter 4 links ancillary sub-models to the core for the various scenarios investigated, which are not discussed here.

Overhead costs in large scale commercial plantations are likely to be a function of farm size, but this has not been investigated further due to a lack of reliable data for *Jatropha* plantations. Sartorius and Kirsten (2004) discover that there are also differences in overhead costs between agricultural crops and timber. It is unknown whether this arises from differences in the administrative cost of the land-use or the respective capital investments, packaging and storage costs, insurance, depreciation or property costs. The model allows for specific accounting of capital and overhead costs or for the user to simply define the total annual cost per hectare of plantation.

Yield response to fertilization and *Jatropha* agronomy in general is poorly understood, thus an estimate for the relative cost of investment versus improvements in yield is not possible at present. It was assumed that fertilizer costs increase linearly with yield based on the premise that an equivalent amount of fertilizer is required to ameliorate the nutrients removed during harvesting. Using estimated seed nitrogen, phosphorus and potassium compositions (Jongschaap *et al*., 2007) the specific mass of nutrient harvested can be determined hence, the equivalent quantities of mineral fertilizer required to substitute these losses and the total cost per hectare per year is calculated. Seedcake could potentially be returned to the field instead of using fertilizers. If this is assumed then seedcake sales cannot be considered as an additional source of factory income. This would also involve transport and handling costs which are not coded features of the model.

Maintenance costs aren't generally anticipated after the tree has been established (Gov. of India, NOVOD Board, accessed online 15/04/2010). During the establishment phase, irrigation, pruning, weeding and pesticide application are very important, in addition to fertilization. It was assumed that it takes 5 years to establish mature yields which increase exponentially up to this point. By that time, the tree should have been pruned to the desired architecture, should be resistant to pests and have sufficient canopy cover to outcompete weeds for sunlight, preventing their succession between tree rows but if anticipated, a steady-state cost for maintenance can be incorporated into the core model.

The establishment phase sub-model is prepared in a format similar to that of a financial ledger. Respective costs and labour requirements are input for each year of establishment and the closing balances are summed. Certain cost variables during establishment are populated automatically by corresponding active sub-models; however, the user still has complete freedom to balance costs and manipulate annual cash flows to reflect their calculated or modelled budgets. Alternately, as with all sub-models, the user can simply define the net establishment balance or annual loan repayment on establishment costs.

Compounding interest on debt is assumed from the first year of establishment and loan repayment on the outstanding balance commences once production is in steady-state. The sub-model exports the net balance at the close of the financial year in which steady-state yields are achieved to another sub-model that allows the user to decide how financing of the loan should take place. The user can dictate the number of years over which the loan is repaid and how frequently repayments will be made, be it annually, biannually, quarterly or monthly. Finally the annual loan repayment can be linked to the core-model, along with the overhead and maintenance costs in a financial steady-state, which accounts for any additional labour man-days to that of the harvesting requirement.

Chapter 4: Modelling the economic returns to labour for *Jatropha* cultivation in southern Africa and India at different local fuel prices[1]

Jatropha curcas L. (*Jatropha*) has emerged as a biodiesel crop of great contemporary importance. The global hype surrounding this crop combined with a relatively poor understanding of its agronomy and unpredictable yields has the potential for unsustainable practice of biodiesel production. The aim of this research is to ascertain if *Jatropha* production could be an appropriate driver for rural development, especially if yields prove to be lower than original predictions. A spreadsheet based financial model has been developed from life-cycle economic analysis of the *Jatropha*-biodiesel production chain to determine if income can support labour wages in southern Africa and India, under local wage legislation, at different yield, production cost and fuel price scenarios. The main assumption of the model is that the biodiesel sales price is proportional to the prevailing petro-diesel price. Results suggest that wage rates in South Africa are too high to support production at the current fuel price. India and Zambia have the potential to generate profits but under specific circumstances; which are a complex function dominated by yield, labour wages, the petroleum-diesel price and the market opportunities for by-products. The validity of the assumptions used in the model needs to be verified with primary data from situation-specific field results; however, the model provides a powerful framework for investigating alternative scenarios and identifying important vulnerabilities and sensitivities, all of which are discussed in this chapter.

1

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4.1. Introduction

Liquid biofuel is one of the fastest-growing markets for agricultural products globally (Fairless, 2007; Matthews, 2007). One feedstock of contemporary importance is *Jatropha* curcas L., (*Jatropha*), which produces inedible oil seeds with good properties for biodiesel production. Due to claims of high yields and wide environmental tolerances (Francis *et al*., 2005; Jongschaap *et al*., 2007) over 900,000 ha have been planted globally to *Jatropha*, with anticipated future plantings estimated at over one million hectares per year (GEXSI, 2008a). This despite very limited data on yields, management requirements and profitability (Achten *et al*., 2007; Fairless, 2007). *Jatropha* is a wild crop in the sense that very limited selective breeding has been undertaken and experience growing this species is highly varied (Achten *et al*., 2010), particularly with regard to yield. Reported yields range from less than 500 kg ha^{-1} to over 12 tonnes, the median of which lies at approximately 2 tonnes per year (see Chapter 2, section 2.3.4, Fig. 2.2), considerably lower than the range of 3 – 5 tonnes predicted by a group of experts in 2007 (EU, 2007) and far lower than the anticipated yields in excess of 5 t ha^{-1} given in many investors' development plans (e.g. D1 Oils Plc (Reuters, accessed online 28/04/2010); Gem BioFuels (accessed online 30/04/2010); Indian Oil Corporation Ltd (accessed online 30/04/2010) and Sun Biofuels Ltd (accessed online 30/04/2010)).

Predominantly, Asia, Africa and Latin America are the regions making significant efforts with 104, 97 and 41 projects having been identified in those respective regions (GEXSI, 2008a). India with 400,000 ha planted, was one of the first countries to embrace *Jatropha*, and has one of the largest areas planted (GEXSI, 2008a). Important African players are Zambia, Tanzania, Madagascar and Mozambique, whilst Brazil is the most important country in terms of area planted in its region of the world (GEXSI, 2008a). Promoters of *Jatropha* motivate that the benefits associated with this biodiesel feedstock are a solution to many of the developing world's socio-economic problems (Jones & Miller, 1992; Newsletter Plant Oil, 1993; GTZ, 1995; GTZ/Rockefeller Foundation, 1995; Heller, 1996; Henning, 1996;

Zimbabwe Biomass News, 1996; Gubitz *et al*., 1997; Openshaw, 2000; Francis *et al*., 2005; GEXSI, 2008b) as it generates high levels of rural employment, improves national balance of trade and stimulates both agricultural and non-agricultural sectors associated with the *Jatropha*-biodiesel production chain.

Jatropha plantations in Africa and India can be characterized according to their scale of production and the markets they target (von Maltitz & Setzkorn, submitted). The types of biofuel projects of interest to this study are those specifically aimed at supporting national and international liquid fuel blends. Projects are thus incentivised by cash from the crop and not by local fuel security (von Maltitz *et al*., 2009). The biofuel industry provides support and inputs, financing, technological assistance and a market (von Maltitz *et al*., 2009). Arguably, biofuels are an attractive farming option on account of the assistance received by the farmers (Haywood *et al*., 2008) in addition to the intrinsic value of the biofuel crop itself. A number of farming models are currently being used and tested in India, which have been discussed by Harrison *et al.* (submitted), and in Africa by von Maltitz and Setzkorn (submitted).

In the first global market study on *Jatropha* conducted by GEXSI (2008a), two-thirds of all projects analysed work with local small-growers, often in combination with managed plantations. Fifty percent of the projects in Asia opted for this approach and 66% in Africa. Production for local markets is more important than export, especially in Asia. The majority of the projects identified have nurseries and apply cultivation techniques such as pruning and fertilization, and approximately half of the projects use some type of irrigation (GEXSI, 2008a). However, many of the especially early project plans suggested that *Jatropha* is a hardy crop that can be grown with very little or no inputs (Jones & Miller, 1992; Heller, 1996; Henning, 1996; Openshaw, 2000).

More recent experience suggests that *Jatropha* responds to management input; it needs to be pruned often initially to establish higher yields, it cannot at present be harvested mechanically, it requires pesticide application and weeding, and the labour requirement during establishment is high (Francis *et al*., 2005; Jongschaap *et al*., 2007; Achten *et al*., 2008). This labour requirement contributes greatly to rural employment but at a significant labour cost which may undermine the profitability of *Jatropha*. For *Jatropha* to reduce poverty and improve rural livelihoods, the biodiesel production chain needs to be profitable enough to sustain the labour cost of production. As a minimum requirement, in commercial plantations where labour is employed, the legal minimum wage rate needs to be supported. For independent pickers and small-scale farmers, income must exceed the opportunity costs of labour. The maximum wage to labour is governed by the production efficiency of the chosen feedstock and the price at which biofuel can be sold. Since liquid biofuel directly replaces fossil fuels its value is effectively set by the prevailing price of the petroleum product, unless distorted by differential taxation or subsidy (Tyner, 2008).

The aim of this research is to ascertain if *Jatropha* production could be an appropriate driver for rural development, especially if yields prove to be lower than original predictions. This research considers the labour wage implications of *Jatropha*-based biodiesel projects in southern Africa and India, under local wage legislation, at different yield, production cost and fuel price scenarios.

4.2. Methods

Southern Africa and India have been targeted for *Jatropha* production, based on a wide range of socio-economic and environmental conditions. Data for three countries were collected through literature review, field visits and stakeholder engagement. South Africa, Zambia and India have all been targeted by investors in biodiesel initiatives, with considerable developments for *Jatropha* having already been made in Zambia and India (GEXSI, 2008a). South Africa has a moratorium on the commercial production of *Jatropha* due to its potential invasiveness, though a number of investors are negotiating on developments (The *Jatropha* Organisation of South Africa, accessed online 04/05/2010). These countries were selected as they represent a spectrum of contrasting local fuel prices and minimum labour wages. South Africa has a relatively low fuel price but high minimum wages, the highest in the region. Wages are significantly less in India and the fuel retail price is state controlled and low. Zambia has slightly higher wage rates than India and comparably the highest fuel price of the three countries. These values are provided in Table 4.1.

A spreadsheet based financial model was developed from life-cycle economic analysis of the *Jatropha*-biodiesel production chain. The main assumption of the model was that the biodiesel sales price is proportional to the prevailing petro-diesel price. The model was used to test the sensitivity of production to various input variables.

4.2.1. Structure of the Model

The model uses a top-down systematic approach to calculate, in series, the maximum price the refinery could charge for biodiesel (factory-gate price), the maximum price that can be offered to farmers for the feedstock (farm-gate price), and finally, the maximum daily wage that can be paid to farm labour. This core model was linked to ancillary sub-models to account for other production and operating costs on the farm. These sub-models can be switched on or off to investigate different scenarios such as an overhead cost, the cost of fertilization, additional maintenance costs, establishment costs and the cost of compounded interest on capital loans. The model allows for sensitivity analysis based on factory costs, by-product sales, yields and management practices.

A baseline scenario for each country was assumed; the plantation being in financial steady-state, at mature plantation yields and without maintenance costs. All parameters other than farm overhead cost, local fuel price and the legal minimum wage were fixed at equivalent rates for all countries, so as not to confound the variables under manipulation. The parameters used are summarized in Table 4.1.

Table 4.1: Parameters used for common variables and for country comparisons

COMMON VARIABLES	UNIT		PARAMETER		REF(S).
seed oil content	% (w w^{-1})		34		[1]
oil density	kg l^{-1}		0.92		[1]
factory annual capacity	l x 10^6		10		
net process. cost [a]	US cents l^{-1}		28		X
esterif. efficiency [b]	% (w w^{-1})		98		[2]
glycerine yield [c]	% (w w^{-1})		10		[2]
glycerine credit	US$ t^{-1}		170		[3]
extract. efficiency [d]	% avail. oil		80		[1]
feedstock per l oil expel.	kg		3.38		X
semi-mech. dehusk. rate [e]	kg hr^{-1}		250		[4]
prevail. crude oil price	US$ bbl^{-1}		~80.00		01/04/10
COUNTRY-DEPENDANT VARIABLES		***S.A.***	***Zambia***	***India***	
local currency		ZAR	ZMK	INR	
exchange rate (US$1)		7.14	4761.90	45.45	01/04/10
min wage	US$ MD^{-1}	8.68	2.81	1.54	[5],[6],[7]
local pump price diesel	US cents l^{-1}	112.3	134.9	83.8	[8],[9],[10]
factory-gate price biodiesel [f]	US cents l^{-1}	62.2	88.6	52.8	[8],[9],[11]
farm-gate price	US cents kg^{-1}	11.3	19.5	8.3	X
farm overhead cost [g]	US$ ha^{-1} yr^{-1}	168	55	33	[12]

Notes: a – cost of raw materials (excl. feedstock), overheads and transport; b – % by weight of oil that will convert to biodiesel; c – % glycerine yield by weight of biodiesel; d – motorized screw press; e – manually operated by 2 labourers; f – equal to BFP diesel; g – overhead costs for Zambia & India were estimated from S.A. using proportions equivalent to the ratios between local min wages. Sources: [1] – Achten et al., 2008; X – authors' estimate/model output; [2] – Bender, 1999; [3] – ICIS.com; [4] – FACT Foundation, 2009; [5] – labour.gov.za; [6] – Gov. Of Zambia, 1997; [7] – Gov. of India, NREGA Act 2005; [8] – DME.gov.za; [9] – ERB, 2010; [10] – IOCL.com; [11] – Gov. of India, 2009; [12] – Sartorius & Kirsten, 2004.

To model the effect of management choices on financial returns to labour, two farming models were compared. The first being a large-scale commercial plantation where labour is employed and the second is for small-scale farmers linked as outgrowers where family labour is used and considered as an opportunity cost. Small-scale farmers were also considered as having no overhead costs. Different cost scenarios were considered to display their respective effects on returns to labour. A summary of the variables used in these two models is provided in Table 4.2. The following sections have been formatted in a structure corresponding to the series of steps in the model.

Table 4.2: Parameters used for farm management and production cost scenarios

STEADY-STATE VARIABLES	**UNIT**	**PARAMETER** *India*	**PARAMETER** *Zambia*	***REF(S)***	**SUB-MODEL ACTIVE** [a] ***in figures...***
Farm overhead cost	US$ ha^{-1} yr^{-1}	33	55	*Table 4.*1	4.2; 4.4; 4.5; 4.6
Fertilizer application					4.4; 4.5; 4.6
cost per kg nutrient [b]	US cents kg^{-1}				
N (Urea)		23	107	*[13],[14]*	
P (SSP)		43	196	*[13],[14]*	
K (MOP)		16	76	*[13],[14]*	
required cost at 1 t ha^{-1} yr^{-1} [c]	US$ ha^{-1} yr^{-1}	26	120	*X*	
Seedcake credit					4.5; 4.6
seed composition	%				
N		5.45		*[1]*	
P		2.55		*[1]*	
K		1.30		*[1]*	
value [d]	US$ t^{-1}	37.85	174.13	*X*	
ESTABLISHMENT PHASE VARIABLES					4.4; 4.5; 4.6
site prep. and planting	MD	137		*[15]*	
plants	US$ ha^{-1}	220		*[15]*	
farm-yard manure	US$ ha^{-1}	44		*[15]*	
fertilizer pre-treatment	US$ ha^{-1}	25		*[15]*	
irrigation	US$ ha^{-1}	44		*[15]*	
year 2 labour	MD	40		*[15]*	
replacing mortalities [e]	US$ ha^{-1}	44		*[15]*	
pruning labour [f]	MD ha^{-1} yr^{-1}	12.5		*[15]*	
loan repayment period	yrs	20		*X*	
finance rate	%	7.0	22.0 [g]	*Y,[16]*	
yield maturation period	yrs	5		*Y*	
SMALL-GROWER VARIABLES					4.3
International poverty line	US$ capita^{-1} day^{-1}	1.25		*[17]*	
Alternate land-use [h]					
crop		pulse	maize	*Y,[18]*	
income	US$ ha^{-1} yr^{-1}	44	62	*Y,[18]*	
household size	heads family^{-1}	4	6	*Y,[18]*	
size of farm	ha	3	10	*Y,[18]*	
Minimum dietary requirement	kcal day^{-1}	1770	1750	*[19]*	
staple crop		rice	maize	*Y,[18]*	
energy per serving	kcal 100g^{-1}	365	86	*[20]*	
required intake	kg head^{-1} yr^{-1}	177	743	*X, X*	
cereal price	US cents kg^{-1}	33	28	*[21],[22]*	

Notes: a – figures which display results based on variables activated through various sub-models; b – cost per kilogram nitrogen (N), phosphorus (P) and potassium (K) based on market prices for urea, single-superphosphate (SSP) and potassium chloride (muriate of potash (MOP)) calculated using known product nutrient compositions; c – annual per ha fertilizer cost calculated from the sum of the products of unit costs and masses required to balance N, P & K removed during harvesting 1t of seed; d – calculated directly from the cost of mineral fertilizer equivalent required to ameliorate nutrients removed during harvesting; e – 20% mortality in first year; f – at rate of 200 trees per labourer per day and based on plantation spacing of 2m x 2m (2500 trees per ha); g – official interest rate for Zambia (not corrected for inflation) only used where specified, alternately assume the rate for India was applied; h – current land-use or next most likely alternate to Jatropha. Sources: [1] – Achten et al., 2008; X – authors' estimate/model output; Y – data collected in the field and/or from stakeholder interviews; [13] – FAO, 2005; [14] – Golden Valley Agricultural Research Trust, cited in JAICAF, 2008; [15] – Gov. of India, NOVOD Board; [16] – Bank of Zambia (www.boz.zm); [17] – Ravallion et al., 2009; [18] – Haywood et al. 2008; [19] – FAO, 2009; [20] - USDA.gov Nutrient Data Laboratory; [21] – Chief-minister speech, 2010; [22] – AfricaNews, 2008.

4.2.2. Modelling the Factory-Gate Price

The main assumption of the model was that the maximum biodiesel factory-gate price is equivalent to the cost of purchasing and importing petroleum-feedstock from international markets. In South Africa this is known as the Basic Fuel Price (BFP). The BFP reflects the realistic cost of importing a litre of oil from international distilleries (DME, accessed online 25/04/2010). The BFP is a fair baseline estimate for the maximum wholesale biodiesel price. Although biofuels may, in the future, receive subsidies and/or rebates on certain taxes and levies (DME, 2007), distribution costs from the factory to the retailer are likely to be similar to that of petro-diesel, as would retail costs. The pump price for petro-diesel in South Africa is calculated from the BFP using a structure of absolute transport and delivery costs and margins. Therefore, in practice, an estimate for the maximum biodiesel factory-gate price can be calculated from prevailing or projected petro-diesel pump prices.

In India, calculating the BFP from pump prices is impossible due to the state imposing maximum retail prices. Consequently, BFP for India was estimated from the trend in statistics of quantities and values of crude oil imported between 2005 – 06 and 2008 – 09 published by the Ministry of Petroleum (Gov. of India, 2009). Scenarios of adjusting factory-gate prices were investigated.

Zambian retail prices are determined through the Cost-Plus Pricing Model (CPM) (ERB, 2005). This model is used to determine prices for each cargo and provides for longer intervals of price stability. It therefore takes into account all costs associated with the purchase of the petroleum-feedstock. The CPM therefore ensures that all costs incurred in the procurement of petroleum-feedstock are recovered through sales of petroleum products. The pump price per litre is equal to the ex-refinery-gate price plus margins and VAT. Various levy percentages contribute to the ex-refinery-gate which account for the costs involved in the procurement of petroleum-feedstock. In Zambia, fuel prices are not regulated across the country, and transportation costs increase prices in remote areas.

4.2.3. Modelling the Farm-Gate Price

The maximum sales price for feedstock from the farm were estimated by the factory-gate price less costs involved in refining and transport. The model calculates costs from generalized relationships between factory size and per unit capacity production costs (see Chapter 3, section 3.2.2, Fig. 3.3). The model allows for this cost to be based on raw cost structures, published regressions (Nguyen & Prince, 1996; Zhang *et al*., 2003b; Haas *et al*., 2006) or user defined values. The modelled factory capacity used for all regions was 10 million litres per year and at 80 % oil extraction efficiency (Table 4.1). At yields of 1 t ha^{-1}, 35,000 ha of *Jatropha* plantations would be needed to support the refinery. Varying the size of the factory has relatively limited impacts on profitability, except where very small-scale processing units are used. The cost of raw materials is related to factory capacity by economies of scale; the greater the quantity of raw materials purchased, the greater the discount in unit price. Maximization of this; however, is in trade-off to the scale of feedstock production necessary to realize capacity, hence the radius of the hinterland and the distance to transport raw material increases. Due to the relatively flat response in net processing costs to changes in capacity, the impact of factory size was not investigated further (Fig. 3.3).

An important component affecting the farm-gate price is the value at which the by-products such as seedcake can be sold. The market for glycerine is known to be highly volatile even though it is used in many food and pharmaceutical products and used in various manufacturing processes (Bender, 1999). With biodiesel production on the rise, the market could become saturated with glycerine supply, hence the demand will decrease and consequently so will market value. Feasibility of biodiesel from soya is made possible by the relatively high value for seedcake as a protein-rich cattle fodder (Taheripour *et al*., 2010). *Jatropha* seedcake is toxic to animals and many *Jatropha* companies' research and development portfolios are searching for cost-effective means to detoxify seedcake for use as animal-feed. *Jatropha* seedcake has a nutritional value that can be used as a substitute to mineral fertilizer and hence has the intrinsic value of the fertilizer it replaces (see Table 4.2). For most model runs *Jatropha* seedcake was given zero value but a scenario of crediting the refinery seedcake sales at a value equal to that of mineral fertilizer equivalents was also considered. The results of which are displayed in Figure 4.6.

4.2.4. Modelling the Maximum Farm Labour Wage

Maximum labour wage was calculated by the farm-gate price minus the farm production costs, divided by the total labour hours for production. This was calculated for different yields and factory-gate prices, and displayed as breakeven plots.

A number of sub-models investigate different farm production costs, such as administrative costs in the form of overheads (Fig. 4.2; 4.4; 4.5; 4.6), use of fertilizer (Fig. 4.4; 4.6) and loan repayments on establishment costs (Fig. 4.4; 4.5; 4.6). These are differentiated between small-scale farmers where family labour is used and larger commercial plantations where labour is employed (see Table 4.2).

Yield response to fertilization and *Jatropha* agronomy in general is poorly understood, thus an estimate for the relative cost of investment versus improvements in yield is not possible at present. It was assumed that fertilizer costs increase linearly with yield based on the premise that an equivalent amount of fertilizer is required to ameliorate the nutrients removed during harvesting. Using known seed nitrogen, phosphorus and potassium compositions the specific mass of nutrient removed can be determined hence, the equivalent quantities of mineral fertilizer required to substitute these losses was calculated (see Table 4.2). Seedcake could potentially be returned to the field instead of using fertilizers. If this is assumed then seedcake sales cannot be considered as an additional source of factory income. This would also involve transport and handling costs that have not been considered in these model runs.

The number of labour man-days required during harvesting was determined by an estimate for picking rate which has been modelled against annual yields. Dehusking is either manual or semi-mechanical. The improvement in the rate of dehusking from manual to commercially available industrial products like the Universal Nut Sheller (Brandis, accessed online 15/01/2010 is three-fold (see Table 4.1).

Harvesting is labour intensive, but harvesting rates are poorly researched. Many reports define a maximum, or an average picking rate, irrespective of seed yields, and it was difficult to ascertain if these are estimates or based on experience or measurement. A synopsis of picking rates is provided in Chapter 3 of the FACT Foundation (2009) *Jatropha* Handbook, ranging between 2 and 10 kg hr^{-1}. By cross-referencing the location of these with complementary yield reports in the literature, and based on primary coupled data, of time taken to harvest yield on day of harvest, at a scientific trial at Ukalinga in Pietermaritzburg, South Africa (Everson *et al*., submitted); picking rate is related to yield by what was assumed to be a function of fruit density. Picking rate improves significantly with an increase in annual yield and subsequent fruiting density, slowing gradually as it approaches an asymptote. An exponential decay function was fitted to the data to provide a tool for extrapolating picking rates from annual seed yields (Fig. 4.1).

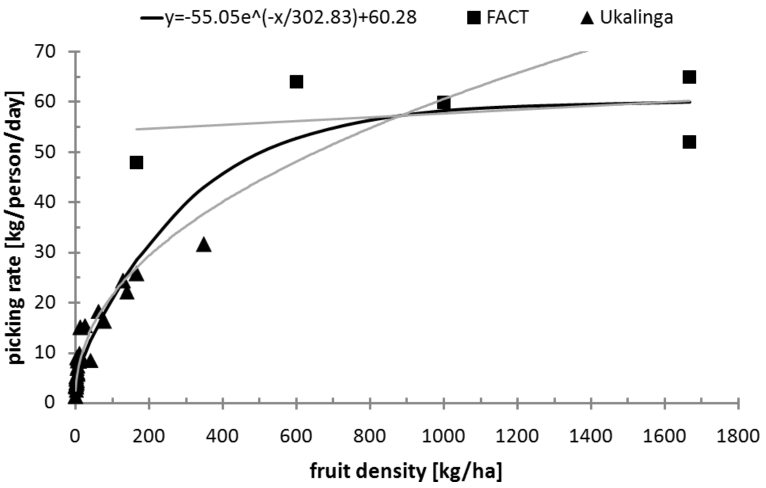

Figure 4.1: Rate of picking (seed) as a function of fruit density during harvest (measured by mean yield on day of harvest). Corresponding yield reports to picking rates expressed in Chapter 3 of the FACT Foundation Jatropha Handbook were divided by 3, as it was the assumed number of harvest events per year. The grey lines are trends fitted to the FACT and Ukalinga data, respectively. Sources: FACT - (FACT Foundation, 2009); Ukalinga - Everson et al., submitted.

By dividing the annual yield by the number of harvest events per year, divided by the picking rate at that fruiting density of harvest, provides the number of labour man-days required per hectare per year.

4.3. Results and Discussion
4.3.1. Mature Plantation Steady-State Financial Viability

The core model simulates the finances of a mature *Jatropha* plantation in steady-state and excludes establishment costs, assumes no fertilizer usage but also excludes potential income from sales of seedcake. Though an over-simplification, this core model provides a baseline against which to assess impacts of introducing other variables. If profitability cannot be shown for this core model, the introduction of all other variables, other than seedcake sale, will further decrease profitability. Outputs from the core model suggest that profitability is strongly influenced by minimum labour wages. In determining profitability (measured as the production of biofuels being able to support labour at higher than minimum wages) the area above the curves (Fig. 4.2) indicate profitability, and below net losses. Indian and Zambian investors are able to break-even at low yields, between 470 and 660 kg ha^{-1} at factory-gate prices equivalent to prevailing petro-diesel, nominally 53 and 89 US cents per litre respectively. South Africa; however, would require a biodiesel factory-gate price 2.7 – 3.6 times greater than the current BFP to support minimum wages at similar yields shown for India and Zambia. Simply put, South Africa mandates too high a wage rate for *Jatropha* production to be economically sustainable at realistically achievable yields. South Africa needs higher fuel prices and relatively high feedstock yields for biodiesel production, of a labour intensive nature, to be financially successful. Due to the inherent unprofitability of South African *Jatropha* production it was excluded from further analyses.

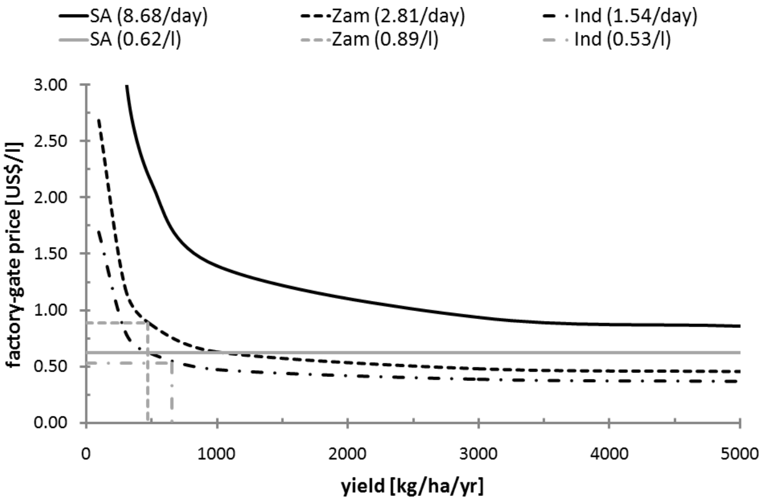

Figure 4.2: Break even plot of complementary factory-gate prices for different yields which support the legal minimum wage payment in South Africa, Zambia and India. Area above the curves indicate net profits, and below; net losses. Values in brackets represent either minimum legal wage or BFP for the respective countries in US$ day^{-1} and US$ l^{-1}, respectively. Scenarios include overhead costs but exclude fertilizer and establishment costs (see Table 4.1).

Yields and financial viability are non-linearly related. The modelled sensitivity of labour wages to changes in yield is most pronounced at yields below 1 t ha^{-1} yr^{-1}, and this is due to the increasing time taken to harvest seeds as fruit density decreases (Fig. 4.1). Increased BFP can compensate for low yields or high labour costs in determining profitability. Though both yield and fuel price have high impacts on returns, profitability is more sensitive to changes in fuel price. Sensitivity analysis for these variables reveals that whilst linear increases in fuel price are met with exponentially increasing rates of return to labour, improvements in yield experience saturating increases to labour wages. This arises from the assumption that a maximum picking rate exists (Fig. 4.1). Profitability is thus constrained by labour. Any technologies that could further increase the speed of picking and dehusking feedstock will improve profitability, but at the cost to labour employed.

4.3.2. Impacts of Yields on Poverty Reduction

From a small-grower perspective, opportunity cost of land and household labour are more important than minimum wages. Where all labour is provided by the household, and assuming there is sufficient available labour, the viability can be measured against poverty lines or the opportunity cost of alternative agricultural land-use. For this the International Poverty Line (BPL – Fig. 4.3), sometimes termed the Starvation Line, which is currently US$ 1.25 per capita per day (Ravallion *et al*., 2009) was considered as a baseline for viability. The model estimates that the current BFP in India supports a farm-gate price of a little under INR 4 (<10 US cents) per kilogram of seed, which is less than the minimum support price of INR 6.50 established by the Chhattisgarh State Government and substantially lower than what is currently offered on the open market, nominally INR 10 – 12 (pers. comm. Chhattisgarh stakeholders). At the modelled feedstock price, a yield of over 5 t ha^{-1} yr^{-1} is needed for a family of four to each individually meet the poverty line and at an opportunity cost of at least 250 man-days of labour (assuming a farm-size of 3 ha; see Table 4.2). For Zambian farmers, on 10 ha land (Table 4.2), just less than 2 t ha^{-1} yr^{-1} would deliver sufficient profits from *Jatropha* to meet the poverty line (Fig. 4.3), but this would require 340 man-days of household labour. The International Poverty Line has been generalized across the globe and may not be the most appropriate measure at the resolution required here.

For small-scale farmers to improve their rural livelihoods by growing *Jatropha* requires financial returns greater than what they achieve from their current land-use. The net annual farm income for small-growers in India and Zambia from existing land-uses was considered, and it was assumed that the only cost for *Jatropha* is the opportunity cost of labour.

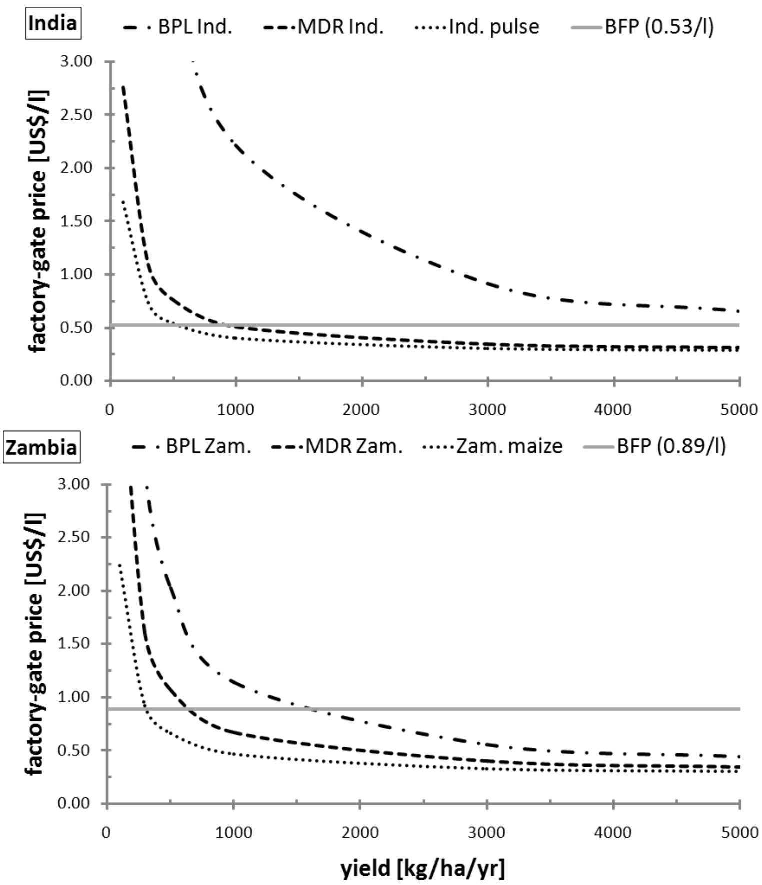

Figure 4.3: Break even plots of complementary factory-gate prices for different yields which support an annual income equivalent to various poverty margins for small-growers in Chhattisgarh, India and Kabwe, Zambia. Series indicate (from left to right): income equivalent to the international poverty line (BPL); income required to purchase of staple crop to meet the minimum dietary requirement (MDR); income equivalent to alternate land-use of pulse-crops or maize; and the BFP for the respective countries. For the parameters of these poverty margins see Table 4.2.

In Chhattisgarh state, India, farmers typically cultivate upland rice, millet, pulses and occasionally some oilseeds (pers. comm. Chhattisgarh stakeholders). It was assumed that *Jatropha* would be used largely on the more marginal areas, replacing low value pulse-crops. Where rice is the staple in India, farmers in Kabwe, Zambia, rely predominantly on maize for subsistence. These farmers generate very modest incomes from these land-uses, on average INR 2000 ha^{-1} (US$ 44)(pers. comm. Chhattisgarh stakeholders) for the sale of pulse crops and ZMK 292,778 ha^{-1} (US$ 62) (Haywood *et al*., 2008) for maize in Zambia (see Table 4.2). Figure 4.3 shows that growing *Jatropha* can generate equivalent incomes from yields below 500 kg ha^{-1}. However, it is usually the case that these existing land-uses are primarily for subsistence and any income received is in surplus to this, thus not reflective of family living costs.

The Food and Agriculture Organization to the United Nations (FAO) publish minimum dietary requirements per person for most countries. In India this is 1770 kcal day^{-1} and in Zambia; 1750 kcal day^{-1} (FAO, 2009). A single serving of 100 g of rice or maize-meal yields 365 and 86 kcal respectively (USDA, accessed online 15/04/2010). Therefore, the required annual consumption per person to meet the minimum dietary requirements in India and Zambia is 177 kg of rice for the former and 743 kg of maize for the latter (see Table 4.2). This does not reflect a balanced nutrition but rather the energy equivalents of the staple crop. At local prices of INR 15 kg^{-1} (33 US cents), excluding transport costs and commission, for rice in Chhattisgarh India (Chiefminister speech, 2010) and 28 US cents kg^{-1} for maize-meal in Zambia (AfricaNews, 2008), *Jatropha* seed sales can match the income required to meet the minimum dietary requirements, of the respective countries, at 800 and 650 kg ha^{-1} yields on 3 and 10 ha farms, respectively (Fig. 4.3).

The minimum dietary requirement cannot be met by a single foodstuff alone as an individual requires a balanced diet of proteins, carbohydrates and fats. It is a useful baseline measure; however, for reflecting the minimum level of *Jatropha* production that would support an income which could warrant replacing an existing land-use. Considering in combination, the ability to purchase staples and the ability to exceed income from alternative crops, it would appear that, provided *Jatropha* yields exceed approximately 1 t ha^{-1}, it could be a viable land-use option. However, measured against the international poverty line, higher yields would be needed to counter poverty. This analysis does not consider the options of intercropping food crops between *Jatropha* rows, or the use of seedcake to enhance crop yields in an agro-forestry faming model. Both options potentially improve the small-holder economics of *Jatropha* production (Achten *et al*., 2010). It is anticipated that in most real-life smallholder farming systems *Jatropha* would only be planted on land in excess of that needed for subsistence needs, or intercropping models would be used.

4.3.3. Impacts of Production Costs on Profitability

Figure 4.4 displays the effect of various production costs on returns to labour. Not surprisingly these additional costs to that of a labour cost have important consequences for plantation feasibility, and substantially higher yields, than those in the steady-state model, are needed before *Jatropha* is viable under prevailing fuel prices. What are significant are the differences between the two countries. Carrying an overhead cost has roughly the same impact on both countries, and the corresponding yields which deliver sustainable wages are very similar despite the almost 100 % difference in local fuel prices. The impact of overhead costs diminishes substantially as yield increases, with overheads having very little impact on profitability at yields over 2 t ha^{-1} in India and 3 t ha^{-1} in Zambia (Fig. 4.4). Overhead costs in large scale commercial plantations are likely to be a function of farm size, but this has not been investigated further due to a lack of reliable data. Whilst Zambia has the higher factory-gate price, India pays lower rates to labour and this moderates the effect that yield has on financial returns to these countries.

Impacts of fertilizer costs are very different between India and Zambia due to the substantially higher price of fertilizers in Zambia. Zambia is landlocked and this would best explain the comparatively higher prices for mineral fertilizer, due to transportation distances. Fertilizer prices are positively correlated to prevailing fuel prices (Kilian, 2009) due to manufacturing and transportation costs, both of which rely on fossil energy, but this feedback mechanism has not been modelled in this research.

The model makes no assumptions relating to the feedback between fertilizer and yield. Where land is not limiting a lower yield without fertilizer may be a better option than a high yield with fertilizer. For instance, in Zambia the steady-state production becomes profitable at 500 kg ha^{-1} without fertilizer (Fig. 4.2), but only at 2.5 t ha^{-1} with fertilizer (Fig. 4.4). If establishment costs are considered then there is a positive cash-flow generated at 1.5 t ha^{-1} without fertilizer, but if fertilizer is added to the equation it doesn't appear possible that projects will be profitable at a realistically achievable yield.

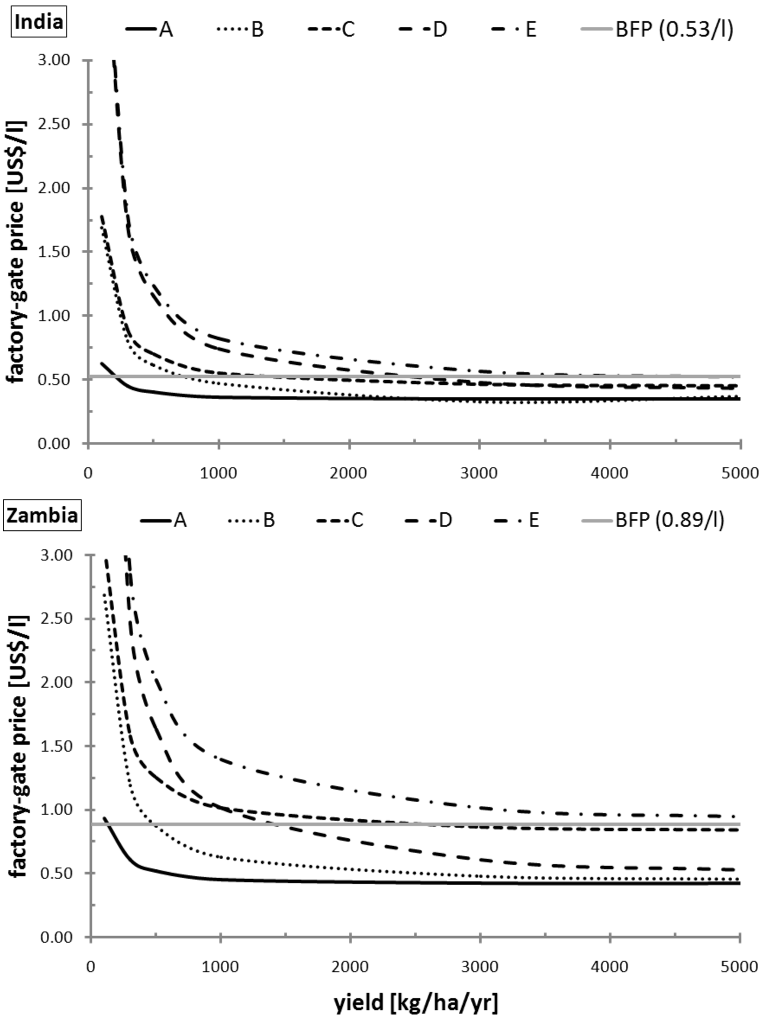

Figure 4.4: Break even plots displaying the effect that various production costs have on the required yield to support minimum wage payments at the current fuel price for India and Zambia. Series indicate (from left to right) cost scenarios of: A – no overhead or any other production costs; B – including overhead cost only; C – including fertilizer costs in addition to overheads; D – overhead cost with inclusion of establishment costs; E – overheads, fertilizer and establishment costs; and the local BFP in US\$ l^{-1}. For the parameters of these respective costs see Table 4.2.

4.3.4. Impact of Financing Costs on Profitability

The effect of having to repay a loan on establishment costs is one of the most important determinants of revenue. It was assumed that money is loaned with compounding interest for plantation establishment and those repayments on the outstanding balance of the loan start in the fifth year when the plantation has been assumed to reach maturity. *Jatropha* plantations in Zambia are able to break even within the first decade if they can achieve a yield of 3 t ha^{-1} without fertilizer application (Fig. 4.5). India requires higher yields to do so. Both countries perform similarly at a yield of 1 t ha^{-1} yr^{-1}, but Zambia generates profits far more rapidly than India at higher yields. This is due to the higher farm-gate price which can be supported in Zambia due to its relatively high fuel price. Maximum yields are assumed after 5 years and both Indian and Zambian plantations display positive cash-flow at 3 t ha^{-1} yr^{-1}, and Zambia will begin turning a profit within the next three years.

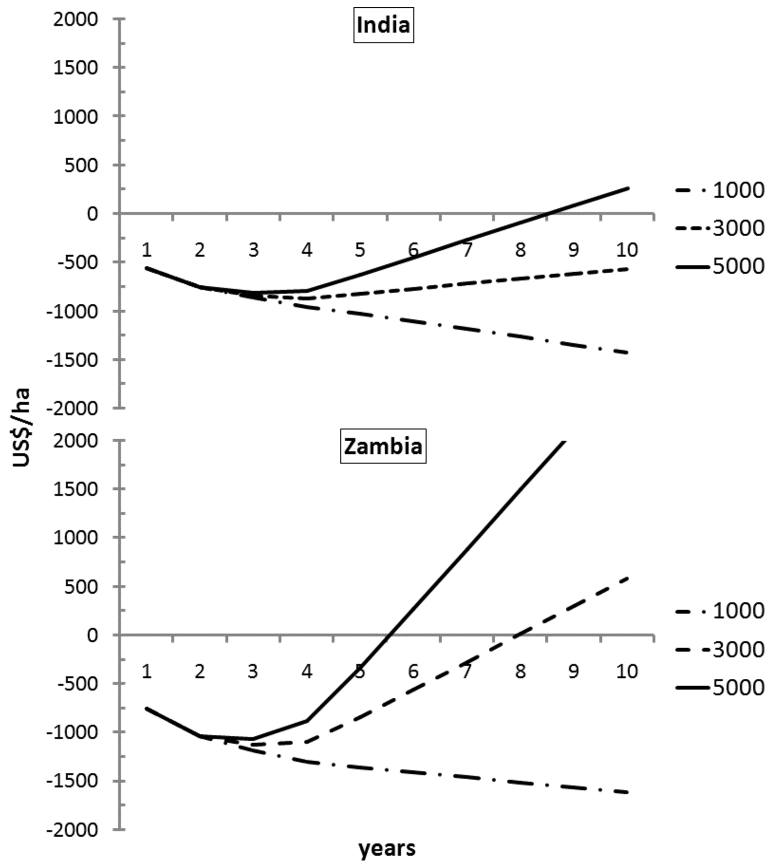

Figure 4.5: Cash-flow over 10 years assuming a loan on capital investment for establishment of the steady-state model (Fig. 4.2) at different yields. The curves indicate the net balance after contiguous years and the slope of the curve is indicative of annual cash-flow, be it positive or negative. Scenarios differ in annual seed yields (kg ha^{-1}); indicated by the legend to the right of each plot. All scenarios include overhead and establishment costs but exclude fertilizer. Loan is financed at 7% compounded interest with quarterly payments for 20 years (see Table 4.2).

If fertilizer, at the level of nutrient loss, is applied, production may never be profitable, as in the Zambian case study, and only if yields are greater than 3.5 t ha^{-1} in India, as displayed in figures 4.4 and 4.6 (scenario E). *Jatropha* seedcake currently has a very low value as a by-product. One option is that seedcake is returned to the plantation, displacing the necessity for mineral fertilizers, and subsequently the cost to the farmer. The alternative is for the mills to sell the seedcake. Currently, the organic fertilizer market is likely to have the greatest demand since seedcake is toxic and cannot at present be used as fodder; however, with regard to its toxicity, the decomposition rate of seedcake and its applicability as a soil ameliorant should be investigated further. If *Jatropha* seedcake is attributed a value equal to that of its mineral fertilizer equivalent, it's role as a by-product may be pivotal in the success of the industry. Crediting the factory sales of seedcake at mineral fertilizer values (see Table 4.2) decreases the net cost of processing enough to allow for markedly higher purchase prices for feedstock. This increases the farm-gate price enough to turn a positive cash-flow at 3 t ha^{-1} in both countries and consequently a return on investment (Fig. 4.6). This is most pronounced for Zambian scenarios due to higher fertilizer values. From a negative cash-flow in Zambia, with fertilizer costs and an annual yield of 3 t ha^{-1} (scenario E, Fig. 4.6), the credit from seedcake sales results in profits being generated after the eighth year of production (scenario E(1)).

The official interest rate in Zambia is very high and drastically inhibits the rate of return on investment (Fig. 4.6: scenario E(1,3)). However, since fuel prices are linked to the US Dollar and considering that a proportion of the high interest rate is driven by high inflation, real rates of interest when working with a Dollar-based commodity may be substantially lower, following the principle of the Fisher hypothesis (Crowder & Hoffman, 1996). The effect of cutting the finance rate, in addition to increased by-product credit to the refinery, provides a positive outcome for *Jatropha*-biodiesel feasibility (scenario E(1,2)).

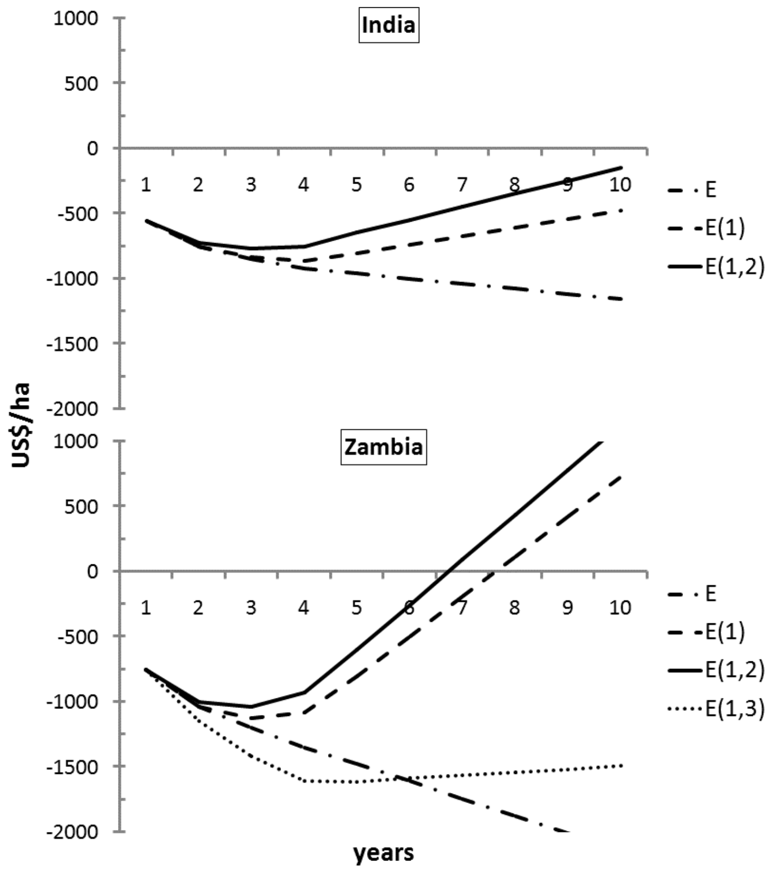

Figure 4.6: The effect of fertilizer, by-product sales and interest rate on cash-flow. All scenarios are modelled at a yield of 3t ha^{-1} yr^{-1}. The uppercase letter in the legend corresponds to that of Fig. 4.4, namely: E – overheads, fertilizer and establishment costs. The numerals alongside in brackets denote: 1 – with seedcake by-product credit to the factory; 2 – at a low interest rate (2%); 3 – at the official Zambian interest rate, not corrected for inflation (22%). Seedcake values for India and Zambia are stated in Table 4.2. Low interest rate was applied to both India and Zambia, a decrease from the current 7% (Table 4.2). The rate of 22% was only applied to Zambia.

Jatropha is thus not a short-to-medium term, high-return crop but dependant on long-term financing at low interest rates for success. Once establishment costs are included in the equation, it requires special circumstances for success; these are highlighted in the conclusions (section 4.4). *Jatropha* would be better described as a high-risk, low-return crop.

4.4. Conclusions

Given the high uncertainty in yields, but a likelihood that yields may be substantially lower than those used in the original business plans (Reuters, accessed online 28/04/2010; Gem BioFuels, accessed online 30/04/2010; Indian Oil Corporation Ltd, accessed online 30/04/2010 and Sun Biofuels Ltd, accessed online 30/04/2010), the modelled results provide a robust mechanism for exploring consequences of variance in yields. These modelled results are dependent on several input assumptions, many of which are generic in nature. Though the validity of assumptions needs to be verified with primary data from situation-specific field results, it provides a powerful framework for investigating alternative scenarios and identifying important vulnerabilities and sensitivities. It is urged that the current results must not be used in isolation to prove or disprove specific project viability, though the model could certainly aid investigators in undertaking such assessments. Many important trends have been identified, namely:

- Yields and financial viability are non-linearly related, most notably at low yields. More data on picking rates under varying yields are required to fully understand this relationship.
- *Jatropha* is most likely to be viable where minimum wages are low; South African wages are simply too high to support a labour intensive *Jatropha*-growing model.
- Profitability is exceptionally sensitive to minimum wages.
- High local fuel prices, for example those in landlocked Zambia, increase the chance of profitability, provided wages are relatively low.
- Yields become very important when factory-gate prices are low.
- Small-scale farmers who carry few overhead costs may be able to make a better income from *Jatropha* than they get from selling their surplus of currently cultivated food-crops, but relatively high yields are needed before *Jatropha*, as a cash crop, can compensate for lost food crop yields.

- For small-scale farmers, the high labour requirements of *Jatropha* harvesting will put substantial constraints on household opportunities. However, if outside labour is employed this will substantially reduce profitability.
- Having to pay back establishment costs greatly reduces the financial viability of projects. Farming models where small scale farmers are provided financial, as well as technical support should be encouraged. If farmers enter into loan agreements to cover the capital costs of establishment, they will be very vulnerable if yields prove to be lower than expected.
- A well paying market for seedcake could greatly alter the economics of *Jatropha* production, but this excludes the option of returning *Jatropha* seedcake to the plantations to compensate for nutrient loss. Using mineral fertilizers greatly increases the yield threshold required for profitability.
- Even as a fertilizer, seedcake could have a relatively high value based on its nutrient composition, if a market is established.
- Lower than expected yield could result in financial disaster to commercial plantations.
- The key cost in *Jatropha* production is labour. *Jatropha* therefore has a better development potential than many other crops (including other biofuel feedstock) where mechanisation and non-labour inputs such as fertilizer contribute the greatest to cost-budgets. However, the ability of the *Jatropha*-biodiesel production chain being able to sustain acceptable labour payment will only be possible under specific circumstances; which are a complex function dominated by yield, minimum labour wages, the petroleum-diesel price and the market opportunities for by-products.

Chapter 5: Discussion on the Theoretical Framework

The fifth and final chapter of this dissertation endeavours to satisfy the third objective outlined in Chapter 1, namely: to discuss the merit of using specific financial returns for labour as a proxy for general economic sustainability assessments. Out of context, economic sustainability is a relatively dimensionless term. This chapter highlights some of the issues in quantifying poverty reduction and economic sustainability, discusses the relevance of the financial model to rural livelihood assessments, and summarizes the research findings.

5.1. The Conceptual and Quantifiable Relevance of the Study

Chapter 4 reveals the effect of local wage legislation on the feasibility of growing *Jatropha* in rural environments for the biodiesel market. The consequences of manipulating system variables on the income generated by rural small-scale farmers and the sustainability of minimum wage payments are also estimated. Where labour is employed on *Jatropha* plantations at the minimum wage, it can be argued that employment is a proponent of poverty reduction. This is assuming that the absolute value of the minimum wage is poverty reducing and that it increases the financial capital to the labourer from their existing source of income. As a caveat to the previous statement, one that will be discussed further at a later stage, whilst a contributor, financial capital is among many complex and almost unquantifiable assets to rural livelihoods (Chambers, 1995; Farina, 2000; Neefjes, 2000; Shackleton *et al*., 2007), many of which compete for labour opportunity (Cousins, 1999).

In the context of the informal sector of small-scale farming, where family labour is used, it may be argued that in the case where *Jatropha*, as a land-use, generates an income greater than a household’s basic living expenditure, cultivation is poverty reducing. This does not take into account the opportunity cost of *Jatropha* cultivation, the area and proportion of land required for cultivation, the seasonality and vulnerability of *Jatropha* as a land-use for sustainable livelihoods, the security of the feedstock market or the profitability of existing and alternate land-uses. Often it is observed that households generate a financial income from their current land-use below that of the international (or locally defined) poverty line (Carter & May, 1999; Haywood *et al*., 2008; see Chapter 4, Table 2.2). Almost 70 % of rural Africans live in households which generate below poverty line incomes (Carter & May, 1999). This reiterates the point that rural livelihoods are sustained by those forms of capital which are not monetized (Chambers, 1995; Cousins, 1999). A reductionist approach for assessing the economics of rural *Jatropha* cultivation requires that income and consumption, which are universal vectors, be measured in monetary values (Chambers, 1995). This may prove to be too simplistic an approach bearing in mind the complex and immeasurable dimensions of sustainable livelihoods.

Absolute poverty refers to the condition of lacking the resources to satisfy basic human needs such as sanitation, nutrition, energy, health care, education, suitable clothing and shelter. Following the definition given by May (1999), poverty is the inability of individuals, households or entire communities to command sufficient resources to satisfy a socially acceptable minimum standard of living. Quantifying an absolute threshold to poverty depends on the determination of the cost of the most essential items consumed by an average individual and the sum of those resources which equate to the minimum expenditure for a tolerable livelihood. This measure is useful for comparing the number of individuals living in poverty between different countries or regions and for monitoring economic development within a region (Chambers, 1995); however, the absolute value is nevertheless challenging to quantify and compare (Townsend, 1993). The relative impacts of poverty tend to be continuous, not discrete, and incomparable between different individuals with different livelihood strategies. In reality the poverty line does not exist as a visible threshold between the poor and the absolutely poor.

Similar difficulties exist for the determination of minimum wages. Although the cost of living is an important component of minimum wage determination (Gov. of India, 1948; Rep. of

South Africa, 1997), wages are also subject to labour market pressures, conditions of employment, the impact of these conditions on the creation of employment in micro, small, medium and new enterprises and the effect of the minimum wage on the ability of employers to continue business successfully (Rep. of South Africa, 1997). The existence of minimum wages may cause business to raise their prices of products or services (propelling inflation), cut down on employment or carry economic inefficiencies by trying to compensate for the increased cost of labour. These are the challenges that are faced when determining the minimum wage, especially in the context of poverty reduction.

Poverty reduction results from providing the poor access to opportunities of economic freedom, hence an income greater than basic needs expenditure (Vásquez, 2001; Krugman, 2009). Considering three-quarters of the world's poor are rural farmers (World Bank, 2008), economic freedom is usually achieved through access to land (Chambers, 1995) and capital for investing in modernized agricultural practices (BBC, 2003; Time, 2009). Fertilizers, pesticides and irrigation systems are important capital investments for improving agricultural output, food security, potential crop surpluses and financial returns. Microloans enable small-scale farmers to purchase materials that they would not have been able to afford, which improve economic rewards by increasing yields. The 2008 World Development Report (World Bank, 2008) identifies support for small-scale farmers as the most important component in the fight against poverty. The agricultural sector has been found to be four times more effective in poverty alleviation and rural development than other sectors (World Bank, 2008). The FAO (2003) define poverty alleviation as a lasting improvement in the livelihood asset base, making households better off than they were before. This definition does not position itself within the context of an absolute poverty margin therefore, by omission, it may be reasonable to interpret poverty reduction, quite simply, as the prevention of intensifying poverty (Shackleton *et al*., 2007).

Economic sustainability criteria as outlined by the Cramer commission (Sustainable Production of Biomass, 2006), the Roundtable on Sustainable Biofuels (2008) and both the

Forest Stewardship Council (FSC, 2002) and CIFOR (1999) criteria and indicators for sustainable natural resource utilization do not assess whether the [*biofuel*] activity is profitable for the farm owner or attempt to quantify whether the livelihoods of the people directly or indirectly involved in the activity are improved, but do provide recommendations and outline criteria for avoiding 'bad practices' of biomass utilization. In response to the third and final objective of this study, quoted at the beginning of this chapter, according to the criteria outlined in the above literature, ensuring that improvements in absolute income are achieved or do not threaten poverty by an absolute income that does not support basic living costs, is sustainable socio-economic practice.

It is the opinion of the author that the complexity of rural livelihood strategies and the appreciation of the importance of natural, human, social and physical capital (Neefjes, 2000) alongside financial capital necessitate extending the economic evaluation of *Jatropha* to its holistic contribution to rural development. An extended discussion will follow in light of this statement.

5.2. The Concept of Sustainable Rural Livelihoods

Norton *et al*. (1994) advise that not all contributions to rural livelihoods are accounted for in income and consumption data surveys because these are not commoditized or easily perceivable to the observer and are thus not evaluated. Another contributing factor to the difficulty of measuring rural economics is the absence of markets (IIED, 1997), the bartering of goods within communities and in-kind contributions paid for opportunity costs (Cousins, 1999). The complexity of evaluating natural resources where markets are not perceivable is further complicated by the diversified use of rural environments. Seasonal effects on natural resource availability force household economies to vary both spatially and temporally (Farina, 2000). However, the collection of natural resources, the tending to fields and the harvesting of foods require significant labour investments, the opportunity costs of which being a significant determinant of where and how labour is invested (Cousins, 1999). As a consequence of the opportunity costs of managing natural resources, the seasonality and spatial variability in natural resource availability and episodic and prolonged periods of stress, rural poverty alleviation is only made possible by increasing total livelihood capital (Neefjes, 2000). Natural resources can be effectively managed and are important safety nets for rural households (Chambers, 1995; Shackleton *et al*., 2007) but cultivation and financial capital intensification are perhaps the only effective mechanisms for sustaining rural livelihoods (Belcher *et al*., 2005).

In the 1990's a sustainable livelihoods framework was developed by the UK Department for International Development (DFID). The framework is still in use as a tool for deconstructing the complexity of livelihoods for our understanding and measurement. At the core of the framework lies the 'asset pentagon'. The asset pentagon takes its shape from the "belief that people require a range of assets to achieve positive livelihood outcomes" (DFID, 1999: Sheet 2.3), categorized into five different capital forms, namely; natural, human, financial, social and physical. Figure 5.1 employs the framework to conceptualize the information reviewed for this study.

The five different types of capital are characteristically different but are nevertheless interconnected. The following definitions are based on DFID (1999). Natural capital incorporates the quality of the environment and is often subdivided into ecosystem goods and services. Examples are those which are stocks of natural resources such as the atmosphere, land, and water for: clean air; terrestrial sources for food, fuel, building materials and shade, livestock; drinking and cooking water, water for crop irrigation, aquatic food resources; and any other respective natural resources. Activities which degrade or improve natural capital are important vectors. Pollution and the quality of soil, water, air, forage, graze palatability and crop nutrition are all important variables. However, many activities convert natural capital to other forms of wealth which may be acceptable trade-offs, for example, agriculture or biofuel feedstock production.

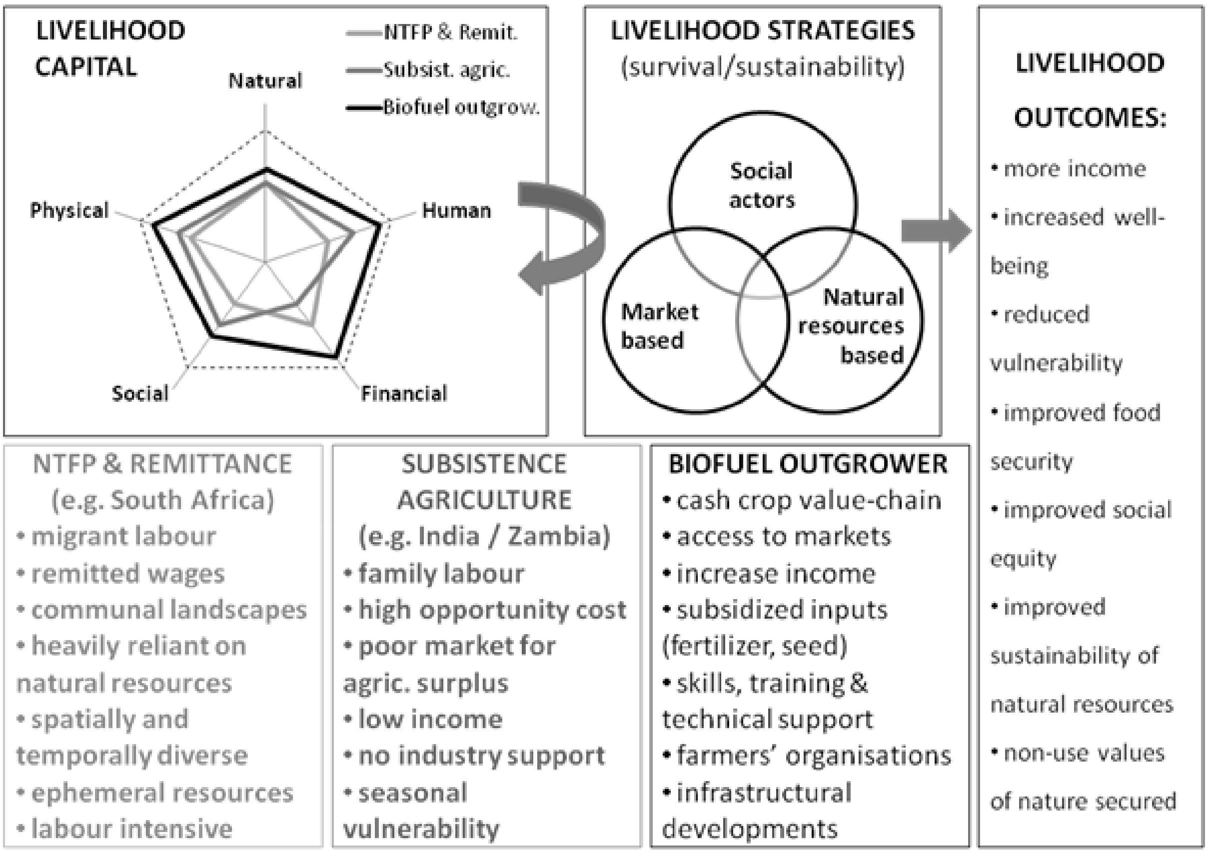

Figure 5.1: The sustainable livelihoods framework. Adapted from DFID (1999), Sustainable Livelihoods Guidance Sheet 2.1. The top portion follows the framework with the inclusion of three different conceptual models in the top-left chart, denoted by the legend. Further descriptions of these respective models are given by the three bottom-left boxes with corresponding titles to the chart legend. NTFP = non-timber forestry products.

Human capital is a measure of the skills and training, and the health and labour capabilities of individuals. Healthcare, education, indigenous knowledge, labour opportunity, scarce skills and technical training are all examples. Within a household, human capital is a factor of the amount and quality of labour available, which varies according to the size of the household, the activities of individual members, the household livelihood strategy and the skills which they have individually learnt and can provide.

Activities which bring in cash income contribute to financial capital. Financial capital is measured by both cash stocks, such as money saved, and regular cash flows, such as wages. Cash income contributes to both production and consumption and is an important asset in the generation of economic freedom for individuals to adopt alternate livelihood strategies or labour activities.

Relationships within social networks, be it those formal or memberships to groups, relationships of trust or a sense of connectedness to individuals with shared interests, are important for sustaining livelihoods. Agents who can be called upon for support through in-kind contributions, those who are a source for companionship and society as a whole that cooperates and adheres to mutually-agreed acceptable behaviours or norms are sources of social capital.

Physical capital is often improved through activities which are primarily aimed at intensifying economies. Infrastructure such as roads, electrification, housing, buildings, sanitation, clinics, schools and crèches are examples of physical capital. Also, producer goods that people use to improve productivity, such as tools or equipment and fertilizers, manure or compost are furthermore, examples of physical capital. Often these examples of physical capital blur the lines of division from natural capital but are in fact given magnitude by the activity of natural capital use.

Non-timber forestry products (NTFP) are an important safety net to rural poor when cash incomes are low. The actual economic value of these resources may be considerable (Wunder, 2001; Belcher *et al*., 2005; Shackleton, 2005) since rural inhabitants rely on the environment for harvestable foods, medicinal plants, building materials, fuel wood, shade, fertilizer and goods which can generate actual cash income (Shackleton, 1997; Cousins, 1999). Subsistence agriculture is the most common livelihood strategy for rural poor globally (World Bank, 2008). The link between natural capital and the 'vulnerability context' (DFID, 1999) is particularly close. Many of the disturbances to natural capital and the sustainability of rural livelihoods are in fact natural processes such as floods, drought, fires, frost and seasonality (DFID, 1999; Neefjes, 2000). In consideration of the previous statement and in reference to figure 5.1, the impacts that the biofuel industry can have on rural livelihoods in southern Africa and India can be considerable. The financial capital of the biofuel outgrower is improved by having access to a market and cash income through feedstock sales. Cash income encourages spending which is important for local economies, increasing the turnover of small commercial sectors of rural areas, such as basic goods stores, garages and repair shops (Shackleton *et al*., 2007). The presence of the biofuel industry may be catalytic in infrastructural developments and the generation of physical capital such as schools and clinics, as has often been delivered by other formal sectors in rural areas such as the forestry and agriculture enterprises (Chambers, 1995; Shackleton *et al*., 2007; World Bank, 2008). Human capital is in turn improved by the opportunity for education and access to healthcare. Skills development, training activities and technical support provided by the biofuel industry (Haywood *et al*., 2008; von Maltitz *et al*., 2009; Harrison *et al*., submitted) further improves human capital. Skills development and financial income might also expand the opportunity for household labour to focus elsewhere or explore further training opportunity or employment. Physical and human capital developments may also give rise to social organisations concerned with education, training, employment and the access to services such as healthcare. If the industry facilitates the establishment of farmers' groups (Harrison *et al*., submitted) social capital will also be increased. Enfranchisement of rural poor can also empower these societies to form greater social networks representative of, for example, the farmers' groups in negotiations with the biofuel industry.

It has been estimated that some 26 % of rural poor in South Africa rely on remitted wages from urban centres as their sole source of cash income (Gov. of South Africa, 2000). Subsistence farmers have poor access to markets for agricultural surpluses (von Maltitz & Brent, 2008; Haywood *et al*., 2008), have little or no support from formal industry, rely on grants and subsidies (Chiefminister speech, 2010) and the opportunity of payment for casual labour (pers. comm. Chhattisgarh stakeholders). The benefits of employment to rural livelihoods are further reaching than cash income (Shackleton *et al*., 2007). Basic conditions of employment often, depending on the state labour law, provide a greater security to employees than simply regular wages, such as pension schemes, vacation leave, sick leave, compensation for work related accidents, unemployment fund contributions and further training opportunities (Shackleton *et al*., 2007).

Scholes (2009) suggests that development is sustainable when the development action does not result in a decrease in the total sum of all livelihood capitals. Hence, a development action whereby natural capital is converted into financial wealth or human well-being is acceptable provided that the loss of natural capital is not greater than the increase in other forms of capital (Scholes, 2009). Introduction of the biofuel industry brings about many positive contributions to the different forms of capital, but is also an example of where conversion of natural capital occurs. Trade-offs between the area of land dedicated to subsistence cropping and the cultivation of *Jatropha* is one reality.

Chapter 4 estimates the level of productivity required for *Jatropha* cultivation to financially warrant displacing the respective existing land-uses of households in India and Zambia, in the context of the International Poverty Line (Ravallion *et al*., 2009) and minimum dietary requirements (FAO, 2009). These respective levels of productivity predict the minimum income from selling *Jatropha* feedstock in India and Zambia that can sustain rural poor at the maximum acceptable risk to livelihoods. In other words, productivity corresponding to revenue below those respective minimum incomes would be at an unacceptable risk to livelihood status. It is important to note that these were estimated by income and consumption data only, and no other livelihood capitals were commoditized. However, the levels of productivity which correspond to those minimum household incomes for India and Zambia require 100 % conversion of natural capital on their respective private land-holdings. Considering the trade-off in natural capital, revealed in the previous statement, and Scholes' hypothesis above (2009) those minimum respective levels of *Jatropha* productivity may in fact be robust estimates of sustainable incomes within the entire livelihoods framework.

Another significant driver for rural economies is the full exploitation of *Jatropha* as a cash crop. Small-scale farmers can market the multiple products provided by *Jatropha* or use these for their own basic needs, particularly the application of *Jatropha* oil and biomass in energy generation (FACT Foundation, 2009) and seedcake for fertilizing fields (Francis *et al*., 2005). *Jatropha* is also believed to reclaim degraded land and control against soil erosion (Heller, 1996; Henning, 1997; Openshaw, 2000; Francis *et al*., 2005; Henning, 2006). Although this research did not attempt to evaluate *Jatropha* as a multi-purpose, multiple product cash crop, it is well appreciated that the species has great potential (Jones & Miller, 1992; Heller, 1996; Henning, 1996; Henning, 1997; Openshaw, 2000; Francis *et al*., 2005; Henning, 2006; Jongschaap *et al*., 2007).

5.3. Summary of the Research Findings

There remains a great deal of uncertainty in the performance potential of *Jatropha* as a biodiesel feedstock, particularly with regard to yields. Avoiding risk of low yields and financial losses, investors may be forced to target less marginal sites and compete with other markets for access to fertile lands. This has implications for the validity of *Jatropha*-biodiesel's widespread sustainability acclaim (Achten et al., 2010).

Yields and financial viability are non-linearly related, most notably at low yields. More data on picking rates under varying yields are required to fully understand this relationship. *Jatropha* is most likely to be viable where minimum wages are low. Small-scale farmers who carry few overhead costs may be able to make a better income from *Jatropha* than they get from selling their surplus of currently cultivated food-crops, but relatively high yields are needed before *Jatropha*, as a cash crop, can compensate for lost food crop yields. Lower than expected yield could result in financial disaster to commercial plantations.

The key cost in *Jatropha* production is labour. *Jatropha* therefore has a better development potential than many other crops (including other biofuel feedstocks) where mechanisation and non-labour inputs such as fertilizer contribute the greatest to cost-budgets. However, the ability of the *Jatropha*-biodiesel production chain being able to sustain acceptable labour payment will only be possible under specific circumstances; which are a complex function dominated by yield, minimum labour wages, the petroleum-diesel price and the market opportunities for by-products.

Absolute poverty refers to the condition of lacking the resources to satisfy basic human needs such as sanitation, nutrition, energy, health care, education, suitable clothing and shelter. Quantifying an absolute threshold to poverty is challenging (Townsend, 1993). The relative impacts of poverty tend to be continuous, not discrete, and incomparable between different individuals with different livelihood strategies.

Often it is observed that households generate a financial income from their current land-use below that of the international poverty line (Carter & May, 1999; Haywood et al., 2008). Financial capital is among many complex and almost unquantifiable assets to rural livelihoods (Chambers, 1995; Farina, 2000; Neefjes, 2000; Shackleton et al., 2007), many of which compete for labour opportunity (Cousins, 1999).

In the 1990's a sustainable livelihoods framework was developed by the UK Department for International Development (DFID). At the core of the framework is the "belief that people require a range of assets to achieve positive livelihood outcomes" (DFID, 1999: Sheet 2.3), categorized into five different capital forms, namely; natural, human, financial, social and physical. The impacts that the biofuel industry can have on rural livelihoods in southern Africa and India can be considerable.

Scholes (2009) suggests that development is sustainable when the development action does not result in a decrease in the total sum of all livelihood capitals. Hence, a development action whereby natural capital is converted into financial wealth or human well-being is acceptable provided that the loss of natural capital is not greater than the increase in other forms of capital (Scholes, 2009). Introduction of the biofuel industry brings about many positive contributions to the different forms of capital, but conversion of natural capital and the trade-off between the area of land dedicated to subsistence cropping and the cultivation of *Jatropha* is one reality.

Although the multi-purpose *Jatropha* production system is not the focus of this research, which is *Jatropha* as a feedstock for the biodiesel market, the application of this crop in rural environments is further reaching. Biofuel cash crops may generate more appeal than food crops due to these incentives provided to the small-grower (Haywood et al., 2008). *Jatropha* cultivation can augment land value by generating income or by directly utilizing *Jatropha* products to displace other basic costs.

References:

1. Achten, W.M.J., E. Mathijs, L. Verchot, V.P. Singh, R. Aerts & B. Muys. 2007. *Jatropha* biodiesel fueling sustainability? *Biofuels, Bioproducts and Biorefining*, **1**: 283-291.
2. Achten, W.M.J., L. Verchot, Y.J. Franken, E. Mathijs, V.P. Singh, R. Aerts & B. Muys. 2008. *Jatropha* bio-diesel production and use, *Biomass & Bioenergy*, **32**(12): 1063-1084.
3. Achten, W.M.J., W.H. Maes, R. Aerts, L. Verchot, A. Trabucco, E. Mathijs, V.P. Singh & B. Muys. 2010. *Jatropha*: From global hype to local opportunity, *Journal of Arid Environments,* **74**: 164–165.
4. Adebowale, K.O. & C.O. Adedire. 2006. Chemical composition and insecticidal properties of the underutilized *Jatropha curcas* seed oil, *African Journal of Biotechnology*, **5**: 901-6.
5. Aderibigbe, A.O., C.O.L.E. Johnson, H.P.S. Makkar, K. Becker & N. Foidl. 1997. Chemical composition and effect of heat on organic matter- and nitrogen-degradability and some antinutritional components of *Jatropha* meal, *Animal Feed Science and Technology*, **67**: 223-43.
6. Adriaans, T. 2006. Suitability of solvent extraction for *Jatropha curcas*. Eindhoven: FACT Foundation.
7. AfricaNews. 2008. Zambia: Maize prices double, Reporting by S, Banda Jr., Wed 2 July, Blantyre, Malawi.
8. Agarwal, A.K. 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, *Progress in Energy and Combustion Science*, **33**: 233-71.
9. Aker, C.L. 1997. Growth and reproduction of *J. curcas*. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 2-18.
10. Akintayo, E.T. 2004. Characteristics and composition of *Parkia biglobbossa* and *Jatropha curcas* oils and cakes, *Bioresource Technology*, **92**: 307-10.
11. Aregheore, E.M., H.P.S Makkar & K. Becker. 1997. Lectin activity in toxic and non-toxic varieties of *J. curcas* using a latex agglutination test. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 65-69.
12. Aregheore, E.M., K. Becker & H.P.S. Makkar. 2003. Detoxification of a toxic variety of *Jatropha curcas* using heat and chemical treatments, and preliminary nutritional evaluation with rats, *South Pacific Journal of Natural Science*, **21**: 50-6.
13. Augustus, G.D.P.S., M. Jayabalan & G.J. Seiler. 2002. Evaluation and bioinduction of energy components of *Jatropha curcas*, *Biomass & Bioenergy*, **23**: 161-4.

14. Azam, M.M., A. Waris, N.M. Nahar. 2005. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India, *Biomass & Bioenergy,* **29**: 293-302.
15. Banerji, R., A.R. Chowdhury, G. Misra, G. Sudarsanam, S.C. Verma & G.S. Srivastava. 1985. *Jatropha* seed oils for energy, *Biomass,* **8**: 277-82.
16. Bank of Zambia. http://www.boz.zm/.
17. Barnwal, B.K. & M.P. Sharma. 2005. Prospects of biodiesel production from vegetables oils in India, *Renewable & Sustainable Energy Reviews*, **9**: 363-78.
18. Batidzirai, B., A.P.C. Faaij & E. Smeets. 2006. Biomass and bioenergy supply from Mozambique, *Energy for Sustainable Development*, **10**(1): 54-81.
19. BBC. 2003. Land rights 'help fight poverty', 20 Jun 2003, http://news.bbc.co.uk/2/hi/business/3006562.stm, accessed 28/07/2010.
20. Beerens, P. 2007. Screw-pressing of *Jatropha* seeds for fueling purposes in less developed countries. MSc dissertation, Eindhoven University of Technology.
21. BEI International. BEI Jatropha Wave Harvester, http://beiinternational.com/uploads/BEI_Jatropha_Wave_Harvester.pdf, accessed 28/07/2010.
22. Belcher, B., M. Ruiz-Pérez & R. Achdiawan. 2005. Global patterns and trends in the use and management of commercial NTFPs: implications for livelihoods and conservation, *World Development*, **33**: 1435-1452.
23. Bender, M. 1999. Economic feasibility review for community-scale farmer cooperatives for biodiesel, *Bioresource Technology*, **70**: 81-87.
24. Benge, M. 2006. Assessment of the potential of *Jatropha curcas*, (Biodiesel tree) for energy production and other uses in developing countries. ECHO's website: http://www.echonet.org/content/article/582/Perspective%20on%20Jatropha%20for%20Biodiesel, accessed 18/08/2006.
25. Biofuels Digest. 2010. Mechanical *Jatropha* harvester successfully trialed in Honduras, http://www.biofuelsdigest.com/bdigest/2010/04/21/mechanical-*Jatropha*-harvester-successfully-trialed-in-honduras/, accessed 28/07/2010.
26. Biswas, S., N. Kaushik & G. Srikanth. 2006. Biodiesel: technology and business opportunities - an insight. In: Singh, B., R. Swaminathan & V. Ponraj, eds. Proceedings of the biodiesel conference toward energy independance - Focus of *Jatropha*, Hyderabad, India, June 9-10. New Delhi: Rashtrapati Bhawan; p. 303-330.
27. BP. 2004. Statistical Review of World Energy 2004, cited in Tobin (2005), http://www.bp.com, accessed 10/2004.

28. Brahmam, M. 2007. Enhancing germination percentage of *Jatropha curcas* L. by presowing. In: Proceedings of the 4th international biofuels conference, New Delhi, India, Feb. 1-2, New Delhi: Winrock International India; p. 175-180.
29. Brandis, J. The Universal Nut Sheller, http://www.thefullbellyproject.org/, accessed 15/01/2010.
30. Carter, M.R. & J. May. 1999. Poverty, livelihood and class in rural South Africa, *World Development*, **27**: 1-20.
31. Chambers, R. 1995. Poverty and livelihoods: whose reality counts? *Environment & Urbanization*, **7**: 173.
32. Chief-Minister speech. 2010. New Delhi, 6 February, http://uti.choice.gov.in:8080/DPR/whoiswho/cm/CM%20Speech,%20New%20Delhi%20060210-%20English, accessed 15/04/2010.
33. Chikara, J., A. Ghosh, J.S. Patolia, D.R. Chaudhary & A. Zala. 2007. Productivity of *Jatropha* curcas under different spacing. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics, Wageningen, The Netherlands, Mar. 26-28, Wageningen: FACT Foundation; p. Article number 9.
34. Chitra, P., P. Venkatachalam & A. Sampathrajan. 2005. Optimisation of experimental conditions for biodiesel production from alkali-catalysed transesterification of *Jatropha curcas* oil, *Energy for Sustainable Development*, **9**: 13-8.
35. CIFOR. 1999. Criteria and indicators: generic template, The criteria and indicators toolbox series, Indonesia.
36. Cousins, B. 1999. Invisible capital: The contribution of communal rangelands to rural livelihoods in South Africa, *Development Southern Africa*, **16**(2): 299-318.
37. Crowder, W.J. & D.L. Hoffman. 1996. The Long-Run Relationship between Nominal Interest Rates and Inflation: The Fisher Equation Revisited, *Journal of Money, Credit and Banking*, **28**(1): 102-118.
38. Daey Ouwens, K., G. Francis, Y.J. Franken, W. Rijssenbeek, A. Riedacker, N. Foidl, R.E.E. Jongschaap & P.S. Binraban. 2007. Position paper on *Jatropha* curcas, State of the art, small and large scale project development, Expert seminar on *Jatropha* curcus L. Agronomy and genetics. 26-28 March, Wageningen, Netherlands, Published by FACT foundation.
39. Dept. of Labour, Rep. of South Africa. http://www.labour.gov.za, accessed 25/04/2010.
40. Department for International Development (DFID). 1999. Sustainable Livelihoods Guidance Sheets, UK Department for International Development.
41. DME. Department of Minerals and Energy to the Republic of South Africa, http://www.dme.gov.za/energy/liquid_petrol.stm, accessed 25/04/2010.

42. DME. 2007. Biofuels Industrial Strategy of the Republic of South Africa, Department of Minerals and Energy to the Republic of South Africa.
43. Echo Bookstore. http://echobooks.org/index.php?cPath=25_152, accessed 02/07/2010.
44. Elsayed, M.A., R. Matthews & N.D. Mortimer. 2003. Carbon and Energy Balances for a Wide Range of Biofuels Options, Resources Research Unit, Sheffield Hallam University, Project No. B/B6/00784/REP URN 03/836 for DTI Sustainable Energy Programmes, Crown: 341pp.
45. Energy Information Association (EIA). 2005. International Energy Outlook 2005, http://www.eia.doe.gov, accessed 01/09/2008.
46. ERB. 2005. Economic Regulation - determination of wholesale prices, Zambia, http://www.erb.org.zm, accessed 15/01/2010.
47. ERB. 2010. Fuel Prices: Wholesale and Provincial Centre, http://www.erb.org.zm/content.php? viewpage=wpfp, accessed 25/04/2010.
48. EU. 2007. Expert Meeting *Jatropha*, Brussels 07/12/07, Directorate E – Biotechnologies, Agriculture, Food.
49. Euler, H. & D. Gorriz. 2004. Case study "*Jatropha curcas*", Frankfurt: Global Facilitation Unit for Underutilized Species and Deutsche Gesellschaft für Technische Zusammenarbeit.
50. Everson, C.S., M.B. Gush & M. Mengistu. Submitted. *Jatropha curcas* – The wonder biodiesel plant – Fact or fiction?
51. E4Tech. 2008. Biofuels review: Advanced technologies overview, Renewable Fuels Agency, Department for Transport, UK, http://www.renewablefuelsagency.gov.uk/sites/renewablefuelsagency.gov.uk/files/_documents/E4tech_Advanced_technologies.pdf
52. FACT Foundation. 2009. *Jatropha* Handbook. 2nd ed. Eindhoven: FACT Foundation.
53. Fairless, D. 2007. Biofuel: the little shrub that could—maybe, *Nature,* **449:** 652–5
54. FAO. 2003. State of the World's Forests 2003: Part II, Selected current issues in the forest sector, Food and Agricultural Organisation (FAO), Rome.
55. FAO. 2005. Fertilizer use by crop in India, Land and Plant Nutrition Management Service Land and Water Development Division, Rome.
56. FAO. 2009. Minimum Dietary Requirements, Food Security Statistics, http://www.fao.org/economic/ess/food-security-statistics/en/, accessed 15/04/2010.
57. Farina, A. 2000. The Cultural Landscape as a Model for the Integration of Ecology and Economics, *Bioscience*, **50**(4): 313-320.
58. Foidl, N., G. Foidl, M. Sanchez, M. Mittelbach & S. Hackel. 1996. *Jatropha curcas* L. as a source for the production of biofuel in Nicaragua, *Bioresource Technology*, **58**: 77-82.

59. Forest Stewardship Council (FSC). 2002. Principles and criteria for forest stewardship, Washington D.C.
60. Forson, F.K., E.K. Oduro & E. Hammond-Donkoh. 2004. Performance of *Jatropha* oil blends in a diesel engine, *Renewable Energy*, **29**: 1135-45.
61. Francis, G., R. Edinger & K. Becker. 2005. A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations, *Natural Resources Forum,* **29**: 12-24.
62. Freedman, B., E.H. Pryde & T.L. Mounts. 1984. Variables affecting the yields of fatty esters from transesterified vegetable oils, *J. Am. Oil Soc. Chem*, **61**: 1638-1643.
63. Gallagher, E. 2008. The Gallagher Review of the indirect effects of biofuels production. Renewable Fuels Agency, UK.
64. Gem BioFuels. http://www.gembiofuels.com/index.php?option=com_content&view=article&id=50&Itemid=58, accessed 30/04/2010.
65. Gerbens-Leenes, W., A.Y. Hoekstra & T.H. van der Meer. 2009a. The water footprint of bioenergy, *PNAS*, early edition www.pnas.org/cgi/doi/10.1073/pnas.0812619106.
66. Gerbens-Leenes, W., A.Y. Hoekstra & T.H. van der Meer. 2009b. Reply to Maes *et al*.: A global estimate of the water footprint of *Jatropha curcas* under limited data availability, *Proceedings of the National Academy of Sciences (PNAS)*, **106**(40): Letter E113.
67. GEXSI. 2008a. Global market study on *Jatropha*, The Global Exchange for Social Investment (GEXSI) prepared for the World Wild Fund for Nature (WWF), London/Berlin.
68. GEXSI. 2008b. *Jatropha* Biofuel 2006-2008, Promoting investments with social and economic benefits, Program 2006, Progress Report and revised program 2007(DRAFT), The Global Exchange for Social Investment (GEXSI), London.
69. Ghosh, A., J.S. Patolia, D.R. Chaudhary, J. Chikara, S.N. Rao, D. Kumar, G.N. Boricha & A. Zala. 2007. Response of *Jatropha curcas* under different spacing to *Jatropha* de-oiled cake. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics, Wageningen, The Netherlands, Mar. 26-28, Wageningen: FACT Foundation; p. Article number 8.
70. Ginwal, H.S., P.S. Rawat & R.L. Srivastava. 2004. Seed source variation in growth performance and oil yield of *Jatropha curcas* Linn. in Central India, *Silvae Genetica*, **53**: 186-92.
71. Gmünder, S.M., R. Zah, S. Bhatacharjee, M. Classen, P. Mukherjee & R. Widmer. 2010. Life cycle assessment of village electrification based on straight *Jatropha* oil in Chhattisgarh, India, *Biomass & Bioenergy*, **34**: 347-355.
72. Gokhale, D. 2009. Biofuel markets Asia and *Jatropha* conference, Jakarta.

73. Gosh, L. & L. Singh. 2007. Variation in rooting response in cuttings of *Jatropha curcas* L. In: National seminar on "*Jatropha* cultivation and Bio-diesel production", Allahabad, India, Jan. 27-28, Allahabad: Utthan - Centre for Sustainable Development & Poverty Alleviation.
74. Gour, V.K. 2006. Production practices including post-harvest management of *Jatropha curcas*. In: Singh, B., R. Swaminathan & V. Ponraj, eds. Proceedings of the biodiesel conference toward energy independance - Focus of *Jatropha*, Hyderabad, India, June 9-10, New Delhi: Rashtrapati Bhawan; p. 223-251.
75. Gov. of India, NOVOD Board. Cost – Economics of various TBO's; *Jatropha*, Ministry of Agriculture, http://www.novodboard.com/cost.htm, accessed 15/04/2010.
76. Gov. of India. 1948. Minimum Wages Act, New Delhi.
77. Gov. of India, National Rural Employment Guarantee (NREGA) Act. 2005. Ministry of Rural Development.
78. Gov. of India. 2009. Basic Statistics on Indian Petroleum & Natural Gas 2008-09, Ministry of Petroleum & Natural Gas , New Delhi.
79. Gov. of South Africa. 2000. Integrated Rural Development Strategy, Government Printer, Pretoria. 53 pp.
80. Gov. of Zambia. 1997. The Minimum Wages and Conditions of Employment Act, Chapter 276, Section 3, amended.
81. GTZ. 1995. Plant oil: a contribution to energy issues and sustainable development, Germany: Eschborn 65760.
82. GTZ/Rockefeller Foundation. 1995. The plant oil initiative, New York: Rockefeller Foundation.
83. Gubitz, G.M., M. Mittelbach & M. Trabi, eds. 1997. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Graz, Austria: Dbv-Verlag.
84. Gubitz, G.M., M. Mittelbach & M. Trabi. 1999. Exploitation of the tropical oil seed plant *Jatropha curcas* L., *Bioresource Technology,* **67**: 73-82.
85. Gush, M.B. 2004. *Jatropha* curcas in South Africa, Interim Knowledge Review and Project, South African Water Research Commission.
86. Gush, M.B. 2008. Measurement of water-use by *Jatropha* curcas L. using the heat-pulse velocity technique, *Water SA*, **34**(5): 579-583.
87. Haas, M.J., A.J. McAloon, W.C. Yee & T.A. Foglia. 2006. A process model to estimate biodiesel production costs, *Bioresource Technology*, **97**: 671-678.
88. Hallowes, J.S. 2007. The crop yield potential and water use of *Jatropha* curcas in South Africa, Water Resources Commission Report, pp 47.

89. Harrison, J.A., S. Tiwari & J.M. Amezaga. Submitted. Stakeholder dynamics in bioenergy feedstock production; the case of *Jatropha* curcas for biodiesel in Chhattisgarh State, India.
90. Haywood, L., G. von Maltitz, K. Setzkorn, N. & Ngepah. 2008. Biofuel production in South Africa, Mozambique, Malawi and Zambia: A status quo analysis of the social, economic and biophysical elements of the biofuel industry in Southern Africa, CSIR Oxfam draft report for comment, Natural Resources and the Environment, CSIR, Pretoria.
91. Heller, J. 1996. Physic nut. *Jatropha curcas* L. Promoting the conservation and use of underutilized and neglected crops, PhD dissertation, Institute of Plant Genetic and Crop Plant Research, Gatersleben, Germany & International Plant Genetic Resource Institute, Rome, Italy, http://www.ipgri.cgiar.org/Publications/pdf/161.pdf
92. Henning, R.K. 1995. Combating desertification - Fuel from *Jatropha* plants. In: UNIDO Symposium on development and utilization of biomass energy resources in developing countries, Vienna, Austria, Dec. Vienna: UNIDO, Environment and Energy Branch, Industrial Sectors and Environment Division.
93. Henning, R. 1996. The *Jatropha* project in Mali, Weissensberg, Germany: Rothkreuz 11, D-88138.
94. Henning, R.K. 1997. Fuel production improves food production: the *Jatropha* project in Mali. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27. Graz, Austria: Dbv-Verlag; p. 92-97.
95. Henning, R.K. 2000. The *Jatropha* Booklet - A guide to the *Jatropha* system and its dissemination in Zambia. 1st ed. Weissensberg: bagani GbR.
96. Henning, R.K. 2006. The *Jatropha* System, cited in Achten et al. (2008), http://www.*Jatropha*.de/, accessed 12/02/2006.
97. Hui. 1996. Bailey's Industrial Oil & Fat Products, New York: Wiley.
98. ICIS. http://www.icispricing.com/il_shared/Chemicals/SubPage506.asp, accessed 02/2010.
99. Indian Council of Agricultural Research (ICAR), cited in Ghosh, A., D.R. Chaudhary, M.P. Reddy, S.N. Rao, J. Chikara, J. B. Pandya, J.S. Patolia, M.R. Gandhi, S. Adimurthy, N. Vaghela, S. Mishra, M.R. Rathod, A.R. Prakash, B.D. Shethia, S.C. Upadhyay, V. Balakrishna, R. Prakash & P.K. Ghosh. 2007. Prospects for *Jatropha* methyl ester (biodiesel) in India, *International Journal of Environmental Studies*, **64**(6): 659-674.
100. Indian Oil Corporation Ltd. http://www.iocl.com/.

101. Indian Oil Corporation Ltd. Govt. biofuels dream fails to take off, http://www.iocl.com/MediaCenter/News.aspx?NewsTypeID=7&NewsID=8477, accessed 30/04/2010.

102. International Council for Research in Agroforestry. A tree species reference and selection guide. *Jatropha curcas*. Agroforestry Database, Prosea. www.worldagroforestrycentre.org/sea/products/afdbases/af/asp/speciesinfo.asp?spid=1013#ecology, accessed 02/07/2010.

103. International Energy Agency (IEA). 2008. Energy technology perspective: scenarios and strategies to 2050, OECD/IEA, Paris.

104. International Institute for Environment and Development (IIED). 1997. Valuing the hidden harvest: methodological approaches for local-level economic analysis of wild resources, Research Series, 3(4). London: IIED.

105. International Land Coalition. http://www.landcoalition.org/cpl-blog/?p=4373#more-4373, accessed 02/07/2010.

106. Ishii, Y. & R. Takeuchi. 1987. Transesterified curcas oil blends for farm diesel engines, *Trans. Am. Soc. Agric. Eng.*, **30**(3): 605-609.

107. JA & UNAC. 2009. *Jatropha*! A socio-economic pitfall for Mozambique. Justiça Ambiental, União Nacional de Camponeses & SWISSAID.

108. JAICAF. 2008. The maize in Zambia and Malawi, Japan Association for International Collaboration of Agriculture and Forestry (JAICAF), Sozosha Ltd. Tokyo.

109. *Jatropha* Investment Fund. http://www.*Jatropha*-investmentfund.eu/en/index.php, accessed 02/07/2010.

110. *Jatropha* Organisation of South Africa, http://www.*Jatropha*.org.za/, accessed 04/05/2010.

111. Johnston, M. & T. Holloway. 2007. A Global Comparison of National Biodiesel Production Potentials. *Environmental Science & Technology,* **41**: 7967-7973

112. Jones, N. & J.H. Miller. 1992. *Jatropha curcas*: a multipurpose species for problematic sites. Washington DC: The World Bank.

113. Jongschaap, R.E.E., R.A.R. Blesgraaf, T.A. Bogaard, E.N. van Loo & H.H.G. Savanije. 2009. The water footprint of bioenergy from *Jatropha curcas* L., *Proceedings of the National Academy of Sciences (PNAS)*, **106**(35): Letter E92.

114. Jongschaap, R.E.E., W.J. Corré, P.S. Bindraban & W.A. Brandenburg. 2007. Claims and facts on *Jatropha curcas* L. Wageningen, The Netherlands: Plant Research International B.V., http://www.fact-fuels.org/media_en/Claims_and_Facts_on_*Jatropha*_WUR? session=isgsklbna58j7grrfst888n5r1017 7.

115. Kandpal, J.B. & M. Madan. 1995. *Jatropha curcas* - a renewable source of energy for meeting future energy needs, *Renewable Energy*, **6**: 159-60.

116. Kaul, S., R.C. Saxena, A. Kumar, M.S. Negi, A.K. Bhatnagar, H.B. Goyal *et al*. 2007. Corrosion behavior of biodiesel from seed oils of Indian origin on diesel engine parts, *Fuel Processing Technology*, **88**: 303-7.

117. Kaushik, N. 2006. Quality planting material and seed standards in *Jatropha curcas*. In: Singh, B., R. Swaminathan & V. Ponraj, eds. Proceedings of the biodiesel conference toward energy independance - Focus of *Jatropha*, Hyderabad, India, 9-10 June, New Delhi: Rashtrapati Bhawan; p. 179-196.

118. Kaushik, N. & S. Kumar. 2006. *Jatropha curcas* L. silviculture and uses. 2nd revised ed. Jodhpur: Agrobios.

119. Kilian L. 2009. Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market, *American Economic Review,* **99**(3): 1053–69.

120. Kpoviessi, D.S.S., G.C. Accrombessi, C. Kossouoh, M.M. Soumanou & M. Moudachirou. 2004. Physicochemical properties and composition of pignut (*Jatropha curcas*) non conventional oil from different regions of Benin, *Comptes Rendus Chimie*, **7:** 1007-12.

121. Krugman, P.R. & R. Wells. 2009. Macroeconomics, 2nd edition, Krugman, P.R. ed., Worth Publishers, New York, pp 524.

122. Kumar, M.S., A. Ramesh & B. Nagalingam. 2003. An experimental comparison of methods to use methanol and *Jatropha* oil in a compression ignition engine, *Biomass & Bioenergy*, **25**: 309-18.

123. Lal, S.B., B. Mehera, R. Chandra & A, Larkin. 2004. Performance evaluation of *Jatropha* curcus in different districts of Uttar Pradesh, *New Agriculturist*, **15**: 141-144.

124. Lepper, H. & L. Friesenhagen. 1986. Process for the production of fatty acid esters of short-chain aliphatic alcohols from fats and/or oils containing free fatty acids. US Patent 4608202.

125. Lopez, O., G. Foidl, N. Foidl. 1997. Production of biogas from *J. curcas* fruitshells. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium "*Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 118-122.

126. Ma, F. & M.A. Hanna. 1999. Biodiesel production: a review, *Bioresource Technology*, **70**: 1-15.

127. Maes, W.H., A. Trabucco, W.M.J. Achten & B. Muys. 2009a. Climatic growing conditions of *Jatropha* curcas L., *Biomass & Bioenergy*, **33**(10): 1481-1485.

128. Maes, W.H., W.M.J. Achten & B. Muys. 2009b. Use of inadequate data and methodological errors lead to an overestimation of the water footprint of *Jatropha curcas*, *Proceedings of the National Academy of Sciences (PNAS)*, **106**(34): Letter E91.

129. Makkar, H.P.S. & K. Becker. 1997. Potential of *J. curcas* seed meal as a protein supplement to livestock feed, constraints to its utilisation and possible stratgies to overcome constraints. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 190-205.

130. Makkar, H.P.S., K. Becker, F. Sporer & M. Wink. 1997. Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas*, *Journal of Agricultural and Food Chemistry*, **45**: 3152-7.

131. Makkar, H.P.S., A.O. Aderibigbe & K. Becker. 1998a. Comparative evaluation of non-toxic and toxic varieties of *Jatropha curcas* for chemical composition, digestibility, protein degradability and toxic factors, *Food Chemistry*, **62**: 207-15.

132. Makkar, H.P.S., K. Becker & B. Schmook. 1998b. Edible provenances of *Jatropha curcas* from Quintana Roo state of Mexico and effect of roasting on antinutrient and toxic factors in seeds, *Plant Foods for Human Nutrition*, **52**: 31-6.

133. Makkar, H.P.S., G. Francis & K. Becker. 2007. Bioactivity of phytochemicals in some lesser known plants and their effects and potential applications in livestock and aquaculture production systems, *Animal*, **1**: 1371-91.

134. Manurung, R. 2007. Valorisation of *Jatropha* curcas using the biorefinery concept. Expert seminar on *Jatropha* curcas L. Agronomy and genetics. 26-28 March, Wageningen, the Netherlands, Published by FACT Foundation

135. Martinez-Herrera, J., P. Siddhuraju, G. Francis, G. Davila-Ortiz & K. Becker. 2006. Chemical composition, toxic/antimetabolic constituents, and effects of different treatments on their levels, in four provenances of *Jatropha curcas* L. from Mexico, *Food Chemistry*, **96**: 80-9.

136. Matsuno, T., U. Ohsawa, H. Toyohara and K. Nishiyama. 1985. Investigation of oil plants and characteristics of some oil plant seeds, *J. Agric. Sci. Japan*, **29**(3): 160-174.

137. Mattana Saturnino, H., D. Dourado Pacheco, J. Kakida, N. Tominaga & N. Poubel Gonzalves, 2005. Cultura do pinhao-manso (*Jatropha* curcas L.), in EPAMIG-CTNM (Eds). Informe Agropecuario: Producao de oleanginosas para biodiesel. Belo Horizonte, Brazil, pp. 44-78.

138. Matthews, J.A. 2007. Biofuels: what a biopact between North and South could achieve, *Energy Policy,* **35:** 3550–70

139. May, J. 1999. Poverty and Inequality in South Africa: Meeting the Challenge, ed., David Phillip, Cape Town, 304 pp.

140. Meher, L.C., D. Vidya Sagar & S.N. Naik. 2006. Technical aspects of biodiesel production by transesterification - a review, *Renewable and Sustainable Energy Reviews*, **10**: 248-68.

141. Messemaker, L. 2008. The Green Myth? Assessment of the *Jatropha* value chain and its potential for pro-poor biofuel development in Northern Tanzania, M.Sc. dissertation, Utrecht University.

142. Naigeon, C. 1987. Pourghère, graine de reliance, *Inter Tropiques*, **7**(22): 25-27.

143. Neefjes, K. 2000. Environments and livelihoods: strategies for sustainability, ed., Oxfam, pp 277.

144. Newsletter Plant Oil. 1993. Engine Development Group, Plant Oil & Engine Development Group, Issue 1 vol. 1. Harare, Zimbabwe.

145. Nguyen, M.H. & R.G.H. Prince. 1996. A simple rule for bioenergy conversion plant size optimization: bioethanol from sugar cane and sweet sorghum, *Biomass & Bioenergy,* **10**(5/6): 361-365.

146. Norton, A., D. Owen & J.T. Milimo. 1994. Zambia Participatory Poverty Assessment, Volume 4 of Zambia Poverty Assessment, World Bank, Washington DC.

147. Oanda Corporation. Forex Trading and Exchange Rates Services, http://www.oanda.com/.

148. Openshaw, K. 2000. A review of *Jatropha curcas*: an oil plant of unfulfilled promise, *Biomass & Bioenergy*, **19**: 1-15.

149. Oxfam. Make Trade Fair, http://www.oxfam.ca/what-we-do/campaigns/make-trade-fair, accessed 28/07/2010.

150. Patolia, J.S., A. Ghosh, J. Chikara, D.R. Chaudhary, D.R. Parmar & H.M. Bhuva. 2007. Response of *Jatropha curcas* grown on wasteland to N and P fertilization. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics, Wageningen, The Netherlands, Mar. 26-28, Wageningen: FACT Foundation; p. Article number 34.

151. Prakash A.R., J.S. Patolia, J. Chikara, G.N. Boricha. 2007. Floral biology and flowering behaviour of *Jatropha curcas*. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics, Wageningen, The Netherlands, Mar. 26-28. Wageningen: FACT Foundation; p. Article number 2.

152. Pramanik, K. 2003. Properties and use of *Jatropha curcas* oil and diesel fuel blends in compression ignition engine, *Renewable Energy*, **28**: 239-48.

153. Prasad, C.M.V., M.V.S.M. Krishna, C.P. Reddy & K.R. Mohan. 2000. Performance evaluation of non-edible vegetable oils as substitute fuels in low heat rejection diesel engines. Proceedings of the Institution of Mechanical Engineers Part D, *Journal of Automobile Engineering,* **214**: 181-7.

154. Rabé, E.L.M., L.M.T. Somers & L.P.H. Goey. 2005. *Jatropha* oil in compression ignition engines - Effects on the engine, environment and Tanzania as supplying country. MSc dissertation, Eindhoven University of Technology.

155. Radhakrishna, P. 2007. Contribution of de-oiled cakes in carbon sequestration and as a source of energy, in Indian agriculture - need for a policy initiative. In: Proceedings of the 4th international biofuels conference, New Delhi, India, Feb. 1-2, New Delhi: Winrock International India; p. 65-70.
156. Raju, A.J.S. & V. Ezradanam. 2002. Pollination ecology and fruiting behaviour in a monoecious species, *Jatropha curcas* L. (*Euphorbiaceae*), *Current Science*, **83**: 1395-8.
157. Rao, G.R., G.R. Korwar, A.K. Shanker & Y.S. Ramakrishna. 2008. Genetic associations, variability and diversity in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) accessions, *Trees Struct. Funct,* **22**(5): 697-709.
158. Ravallion, M., S. Chen & P. Sangraula. 2009. Dollar a day Revisited, *World Bank Economic Review*, **23**(2): 163-184.
159. Reddy, J.N. & A. Ramesh. 2006. Parametric studies for improving the performance of a *Jatropha* oil-fuelled compression ignition engine, *Renewable Energy*, **31**: 1994-2016.
160. Rep. of South Africa. 1997. Basic Conditions of Employment Act, Act No. 75.1997. Government Gazette, 5 Dec 1997.
161. Reuters. 2008. *Jatropha* shines as non-food oil for biodiesel, reporting by Nao Nakanishi, edited by Michael Urquhart, http://www.reuters.com/article/idUSHKG28600520080115, accessed 28/04/2010.
162. Rooney, W.L., J. Blumenthal, B. Bean & J.E. Mullet. 2007. Designing sorghum as a dedicated bioenergy feedstock. *Biofuels, Bioproduction & Biorefining,* **1**: 147-157
163. Roundtable on Sustainable Biofuels. 2008. Global principles and criteria for sustainable biofuels production, Version Zero, pp 9.
164. Royal Society. 2008. Sustainable biofuels: prospects and challenges. The Royal Society, London.
165. Rug, M., F. Sporer, M. Wink, S.Y. Liu, R. Henning & A. Ruppel. 1997. Molluscicidal properties of *J. curcas* against vector snails of the human parasites *Schistosoma mansoni* and *S. japonicum*. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Graz, Austria: Dbv-Verlag; p. 227-232.
166. Sartorius, K. & J. Kirsten. 2004. The cost efficiency of small farm inclusion in agribusiness supply chains, *South African Journal of Accounting Research,* **18**(1):87-113.
167. Schnitzer, M. & S.U. Kahn. 1978. Soil Organic Matter, eds. Elsevier Scientific Pub. Co., Amsterdam; New York, pp 319.
168. Scholes, R.J. 2009. Syndromes of dryland degradation in southern Africa, *African Journal of Range & Forage Science*, **26**(3): 113-125.

169. Searchinger, T., R. Heimlich, R.A. Houghton, F.X. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes & T.H. Yu. 2008. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change, *Science,* **319:** 1238-40.
170. Shackleton, C.M. 1997. The prediction of woody productivity in the savanna biome, South Africa. Phd thesis, University of the Witwatersrand.
171. Shackleton, C.M., S.E. Shackleton, E. Buiten & N. Bird. 2007. The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa, *Forest Policy and Economics*, **9**: 558-577.
172. Shackleton, S.E. 2005. The significance of local level trade in natural resource products for livelihoods and poverty alleviation in South Africa, PhD thesis, Rhodes University. 287 pp.
173. Shah, S., A. Sharma & M.N. Gupta. 2004. Extraction of oil from *Jatropha curcas* L. seed kernels by enzyme assisted three phase partitioning, *Industrial Crops and Products*, **20**: 275-9.
174. Shah, S., A. Sharma & M.N. Gupta. 2005. Extraction of oil from *Jatropha curcas* L. seed kernels by combination of ultrasonication and aqueous enzymatic oil extraction, *Bioresource Technology*, **96**: 121-3.
175. Shanker, C. & S.K. Dhyani. 2006. Insect pests of *Jatropha curcas* L. and the potential for their management, *Current Science*, **91**: 162-3.
176. Sharma, G.D., S.N. Gupta & M. Khabiruddin. 1997. Cultivation of *Jatropha curcas* as future source of hydrocarbon and other industrial products. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas -* Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 19-21.
177. Sharma, N. 2007. Pest disease management. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics, Wageningen, The Netherlands, Mar. 26-28, Wageningen: FACT Foundation, Article number 26.
178. Silveira, J.C. 1934. Contribution à l'étude du Pulghère aux îles du Cap Vert, *An. Inst. Super. Agron. Lisboa,* **6**(1):116-126.
179. Singh, L., S.S. Bargali & S.L. Swamy. 2006. Production practices and post-harvest management. In: Singh, B., R. Swaminathan & V. Ponraj, eds. Proceedings of the biodiesel conference toward energy independance - Focus of *Jatropha*, Hyderabad, India, June 9-10. New Delhi: Rashtrapati Bhawan; p. 252-267.
180. Soares Severino, L., R. de Lourdes Silva de Lima, A.B. Leăo & N.E. de Macedo Deltrăo. 2007. Root system characteristics of *Jatropha curcas* plants propagated through five methods. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics,

Wageningen, The Netherlands, Mar. 26-28. Wageningen: FACT Foundation; p. Article number 31.

181. Staubmann, R., G. Foidl, N. Foidl, G.M. Gübitz, R.M. Lafferty & V.M. Valencia Arbizu. 1997. Production of biogas from *J. curcas* seeds press cake. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 123-131.

182. Stienswat, W., S. Rattanaserikiat & S. Nimunchat. 1986. The studies on growing of physic nut (*Jatropha* curcas) in the large test plot, Research reports on growing of physic nut (*Jatropha* curcas) for diesel fuel substitute [in Thai], Kasetsart University, Bangkok, Thailand.

183. Sujatha, M., T.P. Reddy & M. Mahasi. 2008. Role of biotechnological interventions in the improvement of castor (*Ricinus communis* L.) and *Jatropha curcas* L., *Biotechnol. Adv.* **26**(5): 424-435.

184. Sun Biofuels Ltd. Business Page 7 *Jatropha*. 2009, http://www.sunbiofuels.com/business.html?page=6, accessed 30/04/2010.

185. Sustainable Production of Biomass. 2006. Criteria for sustainable production of biomass, Project Group (Cramer Commission) to the Interdepartmental Programme Management Energy Transition, The Netherlands.

186. Taheripour F., T.W. Hertel, W.E. Tyner, J.F. Beckman & D.K. Birur. 2010. Biofuels and their by-products: Global economic and environmental implications, *Biomass & Bioenergy,* **34**(3): 278-289.

187. Tewari, D.N. 2007. *Jatropha* & Biodiesel. 1st ed. New Delhi: Ocean Books Ltd.: 44.

188. Tigere, T.A., T.C. Gatsi, I.I. Mudita, T.J. Chikuvire, S. Thamangani & Z. Mavunganidze. 2006. Potential of *Jatropha curcas* in improving smallholder farmers' livelihoods in Zimbabwe: An exploratory study of Makosa Ward, Mutoko District, *Journal of Sustainable Development in Africa*, **8**: 1-9.

189. Time. 2009. Next step for microfinance: taking deposits, by Kiviat, B., 30 Aug 2009, http://www.time.com/time/business/article/0,8599,1918733,00.html, accessed 28/07/2010.

190. Tiwari, A.K., A. Kumar & H. Raheman. 2007. Biodiesel production from *Jatropha* (*Jatropha curcas*) with high free fatty acids: an optimized process, *Biomass & Bioenergy,* **31**: 569-75.

191. Tobin, J. & D.J. Fulford. 2005. Life Cycle Assessment of the production of biodiesel from *Jatropha*. MSc dissertation, The University of Reading.

192. Townsend, P. 1999. The International Analysis of Poverty, Harvester Wheatsheaf, New York and London.

193. Tree Oils India Limited. http://www.treeoilsindia.com/, accessed 02/07/2010.
194. Tyner, W.E. 2008. The US Ethanol and Biofuels Boom: It's Origins, Current Status, and Future Prospects, *Bioscience*, **58**(7): 646-653.
195. USDA, Agricultural Research Service, Nutrient Data Laboratory. http://www.nal.usda.gov/fnic/foodcomp/search/, accessed 15/04/2010.
196. Vaitillingom, G. & A. Liennard. 1997. Various vegetable oils as fuel for diesel and burners: *J. curcas* particularities. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 98-105.
197. van Eijk, J. 2006. Transition towards *Jatropha* Biofuels in Tanzania? An analysis with Strategic Niche Management, MSc Dissertation, Eindhoven University of Technology, Department of Technology Management Technology and Policy.
198. Vásquez, I. 2001. Ending mass poverty, US Dept. of State Journal of economic Perspectives, Sept 2001, http://cato.org/research/articles/vas-0109.html, accessed 28/07/2010.
199. von Maltitz, G. P. & A. Brent. 2008. Assessing the biofuel options for Southern Africa, Science real and relevant: 2nd CSIR Biennial Conference, Pretoria, 17-18 November: 16. http://hdl.handle.net/10204/2579, accessed 01/11/2010.
200. von Maltitz, G.P., L. Haywood, M. Mapako & A. Brent. 2009. Analysis of opportunities for biofuel production in sub-Saharan Africa, Environment Brief, CIFOR (CGIAR), Indonesia.
201. von Maltitz, G.P. & K. Setzkorn. Submitted. A typology of southern African biofuel feedstock production projects.
202. Willems, P. 2007. Gas Assisted Mechanical Expression Of Oilseeds, Ph.D. Thesis, University of Twente, The Netherlands. ISBN: 978-90-365-2502-2.
203. Winkler, E., G.M. Gübitz, N. Foidl, R. Staubmann & W. Steiner. 1997. Use of enzymes for oil extraction from *J. curcas* seeds. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27. Graz, Austria: Dbv-Verlag; p. 184-189.
204. World Bank Pink Sheets '03-'09. Commodity Price Data, Development Prospects Group of the Development Economics Vice Presidency, Washington D.C., http://www.worldbank.org/, 01/08/2009.
205. World Bank. 2008 World Development Report 2008: Agriculture for Development. The World Bank, Washington D.C.

206. World Business Council for Sustainable Development (WBCSD) & The International Energy Agency (IEA). 2004. The IEA/SMP Transportation Model, cited in Tobin (2005), http://www.wbesd.org, accessed 03/2005.

207. Wunder, S. 2001. Poverty alleviation and tropical forest—what scope for synergies? *World Development*, **29**: 1817-1833.

208. Zahawi, R.A. 2005. Establishment and growth of living fence species: an overlooked tool for the restoration of degraded areas in the tropics. *Restoration Ecology*, **13**: 92-102.

209. Zamora, E., E. Sobalvarro, R. Norori, G. Foidl & N. Foidl. 1997. Trans-esterification of *J. curcas* oil. In: Gübitz, G.M., M. Mittelbach & M. Trabi, eds. Biofuels and industrial products from *Jatropha curcas* - Proceedings from the Symposium *"Jatropha* 97", Managua, Nicaragua, Feb. 23-27, Graz, Austria: Dbv-Verlag; p. 113-117.

210. Zhang, Y., M.A. Dube, D.D. McLean & M. Kates. 2003a. Biodiesel production from waste cooking oil: 1. Process design and technological assessment, *Bioresource and Technology,* **89**: 1-16.

211. Zhang, Y., M.A. Dube, D.D. McLean & M. Kates. 2003b. Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis, *Bioresource and Technology,* **90**: 229-240.

212. Zimbabwe Biomass News. 1996. Plant oil: Zimbabwe's sustainable fuel for the future, vol. 1 No. 2. Causeway, Zimbabwe: BUN-Zimbabwe.