THE ECONOMIC FEASIBILITY OF ON-FARM BIODIESEL PRODUCTION IN KWAZULU-NATAL, SOUTH AFRICA

By

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DECLARATION

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ABSTRACT

Recent years have seen an unprecedented global increase in the production and use of biofuels. This has been driven primarily by government support for biofuel industries. Soybeans are the only field crop produced in sufficient quantities in the province of KwaZulu-Natal (KZN) that the South African (SA) industrial biofuel strategy identifies as a potential biodiesel feedstock. Thus, this study is an evaluation of the economic feasibility of producing biodiesel on farms from soybeans in the main soybean-producing regions of KZN, using batch processing biodiesel plants. A mixed integer linear programming model was developed to simulate observed agricultural land rental rates (estimated at 4.48% of the market value of land) and cropping behaviour of commercial crop farms in the study regions. The model incorporates various alternative crops, crop rotations, tillage techniques, arable land categories and variance-covariance matrices to account for risk in production. All data are on a real 2009/10 basis.

The model is used to predict possible farmer investment behaviour and determine the minimum biodiesel subsidy required to stimulate soybean-based biodiesel production in the study areas. Results suggest that biodiesel production is currently not an economically viable alternative to fossil fuel, and that the incentives and commitments outlined by the current industrial biofuel strategy are inadequate to both establish and sustain a domestic biodiesel industry. Under baseline assumptions, a realistic minimum implicit subsidy of R4.37 per litre of biodiesel is required to draw soybean-based biodiesel production into the optimum solution for commercial farms.

The economic feasibility of on-farm biodiesel production is highly dependent on the soybean price (i.e., the feedstock input cost) and the soybean oilcake price (i.e., the highest valued by-product). Thus, future promotion of biodiesel ventures could primarily target a reduction of feedstock costs through the development of new technologies which increase yields of available feedstocks and/or permit the use of lower cost alternatives. Higher subsidy levels are anticipated for: (i) small-scale initiatives (particularly in the absence of a rental market for cropland); (ii) soybean-based biodiesel production in areas with less suitable growing conditions for cultivating soybeans; and (iii) using sunflower and/or canola as biodiesel feedstock. To the author's knowledge no other previous studies have attempted to quantify the minimum level of support needed to stimulate biodiesel production in South Africa.

The SA industrial biofuels strategy promotes a development-oriented strategy with feedstock produced by smallholders and processed by traditional producer-owned cooperatives. However, traditional cooperatives suffer from a myriad of institutional problems that are associated with ill-defined property rights. As such, it is argued that these initiatives will fail to attract the capital and expertise needed to process biodiesel. This research, therefore, highlights the need for South Africa's current Cooperatives Act to be amended. Accordingly, this also infers a need to revise the proposed SA industrial biofuels strategy. It is concluded that smallholder participation in biodiesel ventures would require a rental market for cropland, co-ownership of the processing plant in a non-traditional cooperative or investor-owned firm, information and training, and a high level of government subsidy.

This research advocates that government consider promoting soybean oil extrusion ventures as a means of stimulating rural development for small-scale farming initiatives rather than soybean-based biodiesel production, as they will likely require less government assistance, whilst potentially combating the food versus fuel debate against biofuels. This is compounded by the fact that South Africa has historically been a net importer of both soybean oilcake and soybean oil. Importantly, however, the proliferation of such initiatives should not be based on the current notion of traditional cooperatives. The need for government to play a proactive role in such ventures through facilitating the development of appropriate business models which stimulate private investment in feedstock and processing facilities is clearly evident.

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INTRODUCTION

Energy is essential to almost every aspect of both the economic and social development of South Africa (Winkler, 2005). Amigun *et al*. (2008a) note that Africa is endowed with significant quantities of both fossil and renewable energy resources. However, fossil energy resources are unevenly distributed on the African continent, with some 39 African countries being net importers of oil, some of which are among the poorest nations in the world (Mulugetta, 2008). World energy markets are indisputably dominated by the consumption of fossil fuels (Rosegrant *et al*., 2008). Elobeid and Tokgoz (2008: 918) attribute recent interests in biofuels to "environmental, economic, and geopolitical factors". Incentives to develop fuel technologies that utilise agriculturally-based materials as feedstock for renewable energy have thus been attributed to: (i) high and volatile oil and fuel prices; (ii) a growing demand for energy; (iii) increased energy imports; (iv) uncertainties surrounding energy supplies; (v) the desire to establish energy self-reliance and alternatives to fossil fuels; (vi) an increased realization of the negative environmental consequences of fossil fuels; and (vii) a growing interest in supporting farms and rural communities through stronger agricultural markets (Haas *et al*., 2006; Marshall, 2007; Elobeid & Tokgoz, 2008; Rosegrant *et al*., 2008). Although biomass can be utilised for energy in numerous ways, many observers regard biofuels as being the only feasible option for the substitution of fossil fuels, particularly in the transport sector (Peters & Thielmann, 2008).

Biofuels can be classified as any type of solid, liquid, or gaseous fuel that can be produced from biomass substrates, which can be used as a (partial) substitute for fossil fuels (Giampietro *et al*., 1997)[1]. As a general conception, biofuels are obtained from natural sources, are renewable, and can recycle carbon dioxide from their combustion by means of photosynthesis (Escobar *et al*., 2008). Although Petrou and Pappis (2009) note that both virgin and waste biomass can be used as raw material for the production of biofuels, they are currently almost exclusively commercially produced by means of processing agricultural crops (Banse *et al*., 2008), which include maize, oil palm, rapeseed, soybean, sugar beet, sugarcane, wheat, castor beans and *Jatropha carcus* (Escobar *et al*., 2008). Since the most important biofuels are presently bioethanol and biodiesel, Coyle (2007) suggests that the leading feedstocks for current production of biofuels are maize, sugar, and vegetable oils. Soybeans, however, are the only potential biodiesel feedstock (vegetable oil) identified by the

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[1] See Petrou & Pappis (2009) for a comprehensive review of the respective properties, characteristics and production technologies of biofuels.

South African (SA) biofuels industrial strategy grown on a reasonable scale in the province of KwaZulu-Natal (KZN).

An important distinction is made between first, second, and third generation biofuels. First generation biofuels, which are derived from the sugar, starch, or oils in agricultural crops or animal fats, account for all of the current commercial global biofuel production (Senauer, 2008). By comparison, second generation biofuels require advanced conversion technologies (Banse *et al*., 2008), and are expected to make use of a wider range of biomass resources that do not compete directly for food, and could potentially use cellulose from a variety of grasses, maize stover (stalks), and wood (Gurgel *et al*., 2007; Senauer, 2008). They also promise to achieve more significant environmental benefits than their predecessors (Gurgel *et al*., 2007; Banse *et al*., 2008), and have relatively less direct effects on commodity prices (Gurgel *et al*., 2007). However, their commercial viability still has yet to be established (Banse *et al*., 2008; McLaren, 2008; Senauer, 2008). Third generation biofuels are currently still in the research stages, and may utilise substances such as algae, or even feedstocks generated by biotechnology (Senauer, 2008). McLaren (2008) concludes that there remains considerable potential for improvements in both processing methods and the types of feedstocks used for current biofuel production. First generation biofuels (derived from soybeans, for example) may, therefore, function as “transition fuels”, which could meet the short-term needs for renewable energy sources (Nonhebel, 2005: 200). In the longer-term technological advancements, such as the development of second and third generation biofuels, are likely to be necessary to satisfy the increasing demand for renewable energy.

In addition to potentially reducing reliance on finite fossil fuel sources for countries that grow their own feedstocks, and subsequent improved energy security, biofuels could also provide benefits such as increased value of agricultural products and support for farmers and the agricultural sectors of both developed and developing countries (Marshall, 2007). This may be partly attributable to the fact that the emergence of biofuels has represented an alternative market for numerous agricultural commodities (Elobeid & Hart, 2007). Moreover, biofuels could potentially improve agricultural and environmental sustainability through the reduction of greenhouse gas emissions relative to fossil fuels, which is an important component of climate change mitigation (Rosegrant *et al*., 2008). Consequently, there have been considerable developments in the global production, production capacity, and trading volumes of biofuels in recent years (Verdonk *et al*., 2007; Banse *et al*., 2008; Meyer *et al*., 2008; Heinimö & Junginger, 2009). This trend is expected to continue in the future (Verdonk *et al*., 2007; Worldwatch Institute, 2007; Wilson *et al*., 2008; Heinimö & Junginger, 2009; Hoekman, 2009), and is regarded as a potential significant driver of economic growth for some developing countries (De La Torre Ugarte *et al*., 2007; Marshall, 2007; Rosegrant *et al*., 2008), and a means to reduce poverty through the creation of employment opportunities and improve the quality of lives (Rosegrant *et al*., 2008). Similarly, poverty alleviation and the stimulation of economic activity in the former homelands are the explicit primary objectives of the SA biofuels industrial strategy (DME, 2007; Funke *et al*., 2009).

Oil reserves are not uniformly distributed around the world and are not located in areas of highest use (McLaren, 2008). Escobar *et al*. (2008) observe that the countries capable of producing large amounts of biomass are typically not fossil fuel producing nations. Consequently, new countries could potentially enter the global energy market, and in so doing reduce the world's dependence on the relatively few countries with oil reserves. This is particularly pertinent in the tropics and subtropics, which are expected to have a comparative advantage in the production of feedstocks, owing to their relatively high biomass productivity (Marshall, 2007). In this regard, Heinimö and Junginger (2009) suggest that Latin America, Sub-Saharan Africa, Eastern Europe, Oceania, as well as east and north-east-Asia, have considerable potential to become important biomass producers in the long-run. However, not all countries comprise the necessary climatic, topographic, edaphic, and other conditions for extensive biofuel production, given that the economic feasibility of such ventures is typically dependent on feedstock availability and the efficiency of their processing (Escobar *et al*., 2008).

The perception that biofuels can contribute towards achieving solutions to numerous problems, ranging from the greenhouse effect, volatile crude oil prices, energy dependency, and rural development, has resulted in widespread acceptance of, and support for, biofuels among policy makers, scientists, environmentalists, agricultural entrepreneurs, and the general public (Russi, 2008). However, Herndon (2008: 403) suggests that the combination of market-induced and policy-induced factors relating to biofuel expansion have created a "perfect storm" causing dramatic shocks to essentially every crop and livestock producer, and agribusiness. Anderson *et al*. (2008) are of a similar view. Accordingly, Hochman *et al*. (2008) suggest that perhaps no other recent economic development has more significant potential to reshape agriculture and farm policy than the emergence of a large and expanding biofuel industry.

Despite African countries, specifically those in Sub-Saharan Africa, currently being regarded as an unexploited resource for biofuel development (Worldwatch Institute, 2007; Amigun *et al*., 2008a; Mulugetta, 2008), there has been limited research conducted on the feasibility and potential impacts of an expanding biofuel industry on domestic agricultural commodity markets and rural development from a SA standpoint (Amigun *et al*., 2008a; Makenete *et al*., 2008; Meyer *et al*., 2008; Funke *et al*., 2009). Subsequently, the KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development (KZNDAEARD) has expressed interest in, and commissioned research to analyse, the economic feasibility of on-farm biodiesel production in KZN.

It is well documented that biodiesel is typically more costly to produce than conventional diesel, and numerous studies elsewhere have suggested that government interventions in the form of tax incentives and/or subsidies would be necessary for biodiesel to become competitive with conventional diesel (Ahouissoussi & Wetzstein, 1997; Bender, 1999; Fortenberry, 2005; Wassell & Ditmer, 2006; Demirbas, 2007; Martinez-Gonzalez *et al*., 2007; Amigun *et al*., 2008b; Peters & Thielmann, 2008). Therefore, in this study it is hypothesized that on-farm biodiesel production in KZN, at both the commercial and small-scale level, is currently not an economically viable alternative to fossil fuels (accounting for the costs and benefits from the perspective of private farms). Should the SA government wish to promote biodiesel production, then considerable public support, in terms of subsidies and/or other incentives, will be required to induce commercial and small-scale farms in KZN to produce biodiesel.

The specific research objectives of this study are, therefore, to (i) present an objective and comprehensive compilation of the economic literature dealing with global biofuel initiatives and resulting implications, with a particular focus on the associated biofuel policy spectrum; (ii) provide empirical results on the economic feasibility of soybean-based biodiesel production on both commercial and smallholder farms in the soybean production regions of KZN; (iii) estimate the minimum level of government incentives required to promote on-farm biodiesel production in these areas; and (iv) evaluate alternative development-oriented cooperative models, with a specific emphasis on their application to SA biofuel ventures. It is not, however, the intention of this study to examine the economic viability of biodiesel production in South Africa at the national level due to the cost and benefit valuation difficulties involved. This is beyond the scope of this study.

The outline of the dissertation is as follows: Chapter 1 examines the past, present, and probable future increases in global production of biofuels, and the potential implications these may have from an environmental and social standpoint. It is these issues which have undoubtedly contributed to biofuels being of such significant global interest in recent times. The biofuel policy spectrum, global trends, and their potential impacts are evaluated in Chapter 2. Given the focus of this study, Chapter 3 analyses some technical and economic issues pertaining specifically to biodiesel production. Chapters 4 and 5 outline the development of the baseline on-farm biodiesel production model, with simulation results and economic analyses for the commercial farm level being presented in the latter. A normative economic evaluation of potential collective small-scale biodiesel production in KZN is discussed in Chapter 6. The dissertation ends with conclusions and policy recommendations, and a summary.

CHAPTER 1: GLOBAL BIOFUEL EXPANSION AND IMPLICATIONS

Recent years have seen an unprecedented increase in the production and use of biofuels. Future projections suggest that this global trend will continue. Therefore, the question is not whether biofuels will play an increasingly prominent role in world energy balances, but rather what the short- and long-term implications of their use will be. Accordingly, this chapter presents a review of some of the more prominent international debates and deliberations surrounding a rapid expansion of biofuel production levels, with particular emphasis placed on social and environmental considerations. These issues have served as catalysts that have sparked wide and growing interests in biofuels.

1.1 Growth of Global Biofuel Production

The global production of biofuels rose substantially between 2004 and 2008, with biodiesel production increasing six-fold and bioethanol production doubling in this period. This translates into total biofuel production increasing from an estimated 33.2 billion litres in 2004 to approximately 79 billion litres in 2008 (Martinot, 2005, 2007, 2009). The vast majority of this production, however, stems from the United States (U.S.), Brazil, and the European Union (E.U.), accounting for 43, 32, and 15 percent of 2007 global biofuels production, respectively. The remaining amount was spread among various other countries, mostly in Asia and Latin America (Coyle, 2007). Figure 1.1 depicts the rapid growth in global biofuels production for this five-year period. However, it is important to note that presently the contribution of biomass in meeting global energy demand is modest (de Fraiture *et al.*, 2008). For example, in 2007 biofuels accounted for less than three percent of the world's transportation fuel requirements (Coyle, 2007; Sexton *et al.*, 2009). Despite this, Schmitz *et al.* (2007) anticipate that biofuels may have a positive long-term impact of lowering fuel prices, where even a small price effect translates into a relatively large consumer gain, because of the large volume of fuel consumed.

The initial shift towards the production of biofuels was in response to high oil prices in the 1970s and 1980s as a consequence of supply restrictions imposed by the Organisation of Petroleum Exporting Countries (OPEC) cartel (Martinez-Gonzalez *et al.*, 2007; Schmitz *et al.*, 2007; Banse *et al.*, 2008). These high oil prices encouraged innovations in oil-saving technologies and prompted many governments (particularly those in countries which are highly dependent on the movement of oil prices) to stimulate the production and use of renewable energy alternatives, such as biofuels (Martinez-Gonzalez *et al*., 2007; Banse *et al*., 2008). Government intervention in these markets subsequently resulted in global bioethanol production reaching approximately 15 billion litres as early as 1985 (Banse *et al*., 2008).

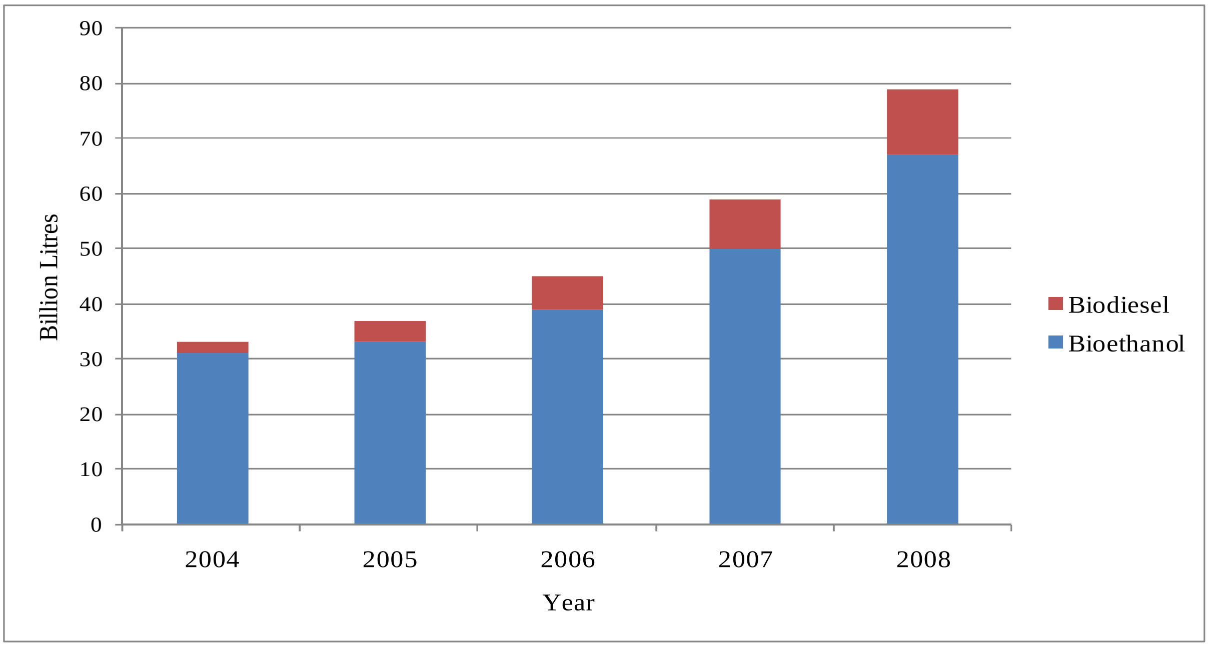

Figure 1.1: Global Biofuel Production, 2004-2008

Source: Martinot (2005, 2007, 2009).

Similarly, Coyle (2007) and Senauer (2008) suggest that the most significant driver of the recent increases in global biofuel production has been the rising real oil price. Cassman and Liska (2007) attribute these price increases to political instability in major oil-exporting regions, and rapid growth in demand in China, India, and other developing countries. However, numerous countries encourage biofuel production through policy measures including subsidies, tax exemptions, mandates, and other government incentives (Kenkel & Holcomb, 2006; Senauer, 2008), which have created favourable market conditions for the production of biofuels (Eidman, 2007). Examples include the National Alcohol Program (PROALCOOL) in Brazil, the Energy Policy Act of 2005 in the U.S., and the 2003 Renewable Fuels Directive in the European Union (Elobeid & Hart, 2007; Elobeid & Tokgoz, 2008).

By far the largest volume of biofuel production is contributed by bioethanol (see Figure 1.1). Globally, bioethanol production is largely concentrated in Brazil and the U.S., which together accounted for nearly 90 percent of total production in 2005 (Rajagopal & Zilberman, 2007). Furthermore, bioethanol production capacities in both these regions continue to increase rapidly (Senauer, 2008). Currently, however, Brazil enjoys a significant comparative advantage in the production of bioethanol from sugarcane (Martinez-Gonzalez *et al*., 2007; Elobeid & Tokgoz, 2008; Sheldon & Roberts, 2008), and it is substantially more efficient than the production of maize-based U.S. bioethanol (Senauer, 2008). Nevertheless, the U.S. is regarded as the largest bioethanol producer in the world (Elobeid & Tokgoz, 2008; Martinot, 2009); although an increasing number of countries are taking a greater interest in bioethanol as an alternative fuel, such as China, India, Canada and France (Elobeid & Hart, 2007; Martinot, 2009).

By comparison, biodiesel production is geographically concentrated within the E.U. countries, derived primarily from rapeseed, with Germany being the world's largest biodiesel producer (Rajagopal & Zilberman, 2007; Schlegel & Kaphengst, 2007; Banse *et al*., 2008b; Martinot, 2005, 2007, 2009). Escobar *et al*. (2008) point out that although European countries produce comparatively more biodiesel than bioethanol, total production of both fuels can be considered as relatively small compared to bioethanol production in Brazil and the U.S. In fact, biodiesel production in the U.S. is approximately seven percent of their bioethanol production (Hoekman, 2009). Nevertheless, Kenkel and Holcomb (2006) and Elobeid and Hart (2007) observe that biodiesel production is gaining increasing importance in the U.S. and South American counties. Elobeid and Hart (2007) suggest the reason biodiesel production has lagged behind that of bioethanol can largely be attributed to their comparatively higher feedstock costs. Interestingly, Eidman (2007) points out that the supply of biodiesel feedstock is a significant limiting factor on the development of the biodiesel industry in the U.S.

In terms of future outlook, the Renewable Fuels Standard of the 2007 U.S. Energy Independence and Security Act set a target of producing 36 billion gallons of biofuels by 2022 (Senauer, 2008; Velasco, 2008; Kenkel & Holcomb, 2009). This established the largest increase of a biofuels mandate in history (Velasco, 2008). This Act stipulates further that almost half of the mandated use of renewable fuels is required to be met by second generation biofuels such as cellulosic bioethanol (Sheldon & Roberts, 2008; Tokgoz *et al*., 2008; Velasco, 2008 Kenkel & Holcomb, 2009). Kenkel and Holcomb (2009) contend that meeting this Act will require capital investments exceeding $100 billion for production facilities, transport and storage infrastructure, and feedstock establishment. Similarly, the E.U. has an established goal of 5.75 percent of transportation fuel by 2010 and 10 percent by 2020 (Senauer, 2008). Numerous other countries have also set biofuel targets (Coyle, 2007) (see Appendix A). While the growth of biofuels production in the U.S. and E.U. may be slowing (Senauer, 2008), the overall trend of increased global biofuel production is expected to continue in the future (Eidman, 2007; Verdonk *et al.*, 2007; Wilson *et al.*, 2008; Heinimö & Junginger, 2009; Hoekman, 2009).

Coyle (2007) suggests that the future outlook for global biofuel production will likely depend on numerous interrelated factors, such as oil prices, the availability and cost of suitable feedstocks, sustained governmental support, technological advancements that improve the feasibility of second generation biofuels, and competition from unconventional fossil fuel alternatives. Walsh *et al*. (2007) contend that the feedstocks necessary to produce biofuels will come largely from the agricultural and forestry sectors. In this regard, De La Torre Ugarte *et al*. (2007) suggest that agriculture is well positioned as a feedstock source. However, such a large expected increase in biofuel production raises numerous questions with regards to the feasibility, approach, and potential impacts of such activities (Walsh *et al*., 2007), particularly the potential social and environmental implications of such widespread biofuel expansion (Marshall, 2007; Worldwatch Institute, 2007). Mulugetta (2008) concurs, suggesting that the decision to expand biofuel production is not based upon economic concerns alone, as there are a number of broader issues such as land use changes, potential conflicts with food production, deforestation, loss of biodiversity, and effects on water tables that need to be taken into consideration. These are the focus of the following sections.

1.2 The Food versus Fuel Debate

While the rapid growth of biofuel production in recent years has raised expectations about possible substitutes for fossil fuels, there have been considerable and growing concerns over the potential negative implications of diverting food crops for the production of biofuels, and subsequent rises in commodity prices, will have on global food and related markets, as well as food security (Coyle, 2007; Worldwatch Institute, 2007; Pingali *et al*., 2008). Escobar *et al*. (2008) suggest that given the large tracts of land demanded to grow biofuel crops, it has become increasingly important to understand the relationship between extensive biofuel production and global rises in food prices. Food crops currently used in the production of first generation biofuels include grains (maize, sorghum, and wheat), sugar crops (sugarcane, sweet sorghum, and sugar beet), starch crops (cassava), and oilseed crops (soybean, rapeseed, and oil palm) (Cassman & Liska, 2007).

Prior to the emergence of biofuels, agricultural commodity prices were influenced by energy prices primarily through their impacts on the costs of production by way of input prices, such as diesel, fertilizers and pesticides (Elobeid & Hart, 2007; Tokgoz *et al*., 2008). Energy prices would also influence food prices through processing and distribution costs (Senauer, 2008). However, significantly higher energy prices are now having a more direct effect on agricultural output prices, since agricultural commodities have become inputs for the production of energy (Elobeid & Hart, 2007; Tokgoz *et al*., 2008). In so doing, they have caused energy and agricultural commodity markets to converge, ultimately creating a food versus fuel trade-off (Cassman & Liska, 2007; Sexton *et al*., 2009; Skipper *et al*., 2009). Similarly, Rosegrant *et al*. (2008) note that major agricultural commodity prices have increased significantly since 2002, and show an increased correlation with oil prices in recent years, depicted in Figure 1.2. Furthermore, Harrison (2009) observed that while prices of agricultural commodities have historically been volatile, many prices in 2007/08 peaked at, or near, record levels.

The growing dependence of agriculture on energy markets has contributed to apprehensions that high and volatile energy prices may create new, or augment existing, food security problems (Schmidhuber, 2006). Thus, Tyner and Taheripour (2008a) regard this new market integration as possibly the most fundamentally important change to occur in agriculture in decades. Pingali *et al*. (2008), however, suggest that while such concerns have their merits and are indeed serious, it is important to note that even in the absence of biofuels, agriculture has traditionally produced both food and non-food commodities (e.g., cotton and tobacco), and that the global agricultural system has historically responded to changing patterns of demand.

Senauer (2008) proposes that previous spikes in world agricultural commodity prices, post World War II, have been supply-driven as consequence to poor harvests in one or more major producing regions; for this reason they have typically been short-lived, before returning to historical levels. The preceding long-term trend was that of decreasing real prices of major food crop commodities such as maize, wheat, rice, and sugar (Cassman & Liska, 2007). This may be attributed to continued improvements in technology, agricultural production and trade. However, the recent price increases are demand-driven, implying that high prices may be sustained for longer periods (Anderson *et al*., 2008; Senauer, 2008). Nevertheless, the Worldwatch Institute (2007: 135) contends that "such increases in the demand for, and price of, food crops have been a deliberate and fundamental motivation of biofuel programmes as governments aim to protect farmers from excessively low prices". Interestingly, however, Senauer (2008) suggests that a serious U.S. and global economic slowdown could be the one factor that would sharply decrease commodity prices, evidence of which is apparent in Figure 1.2.

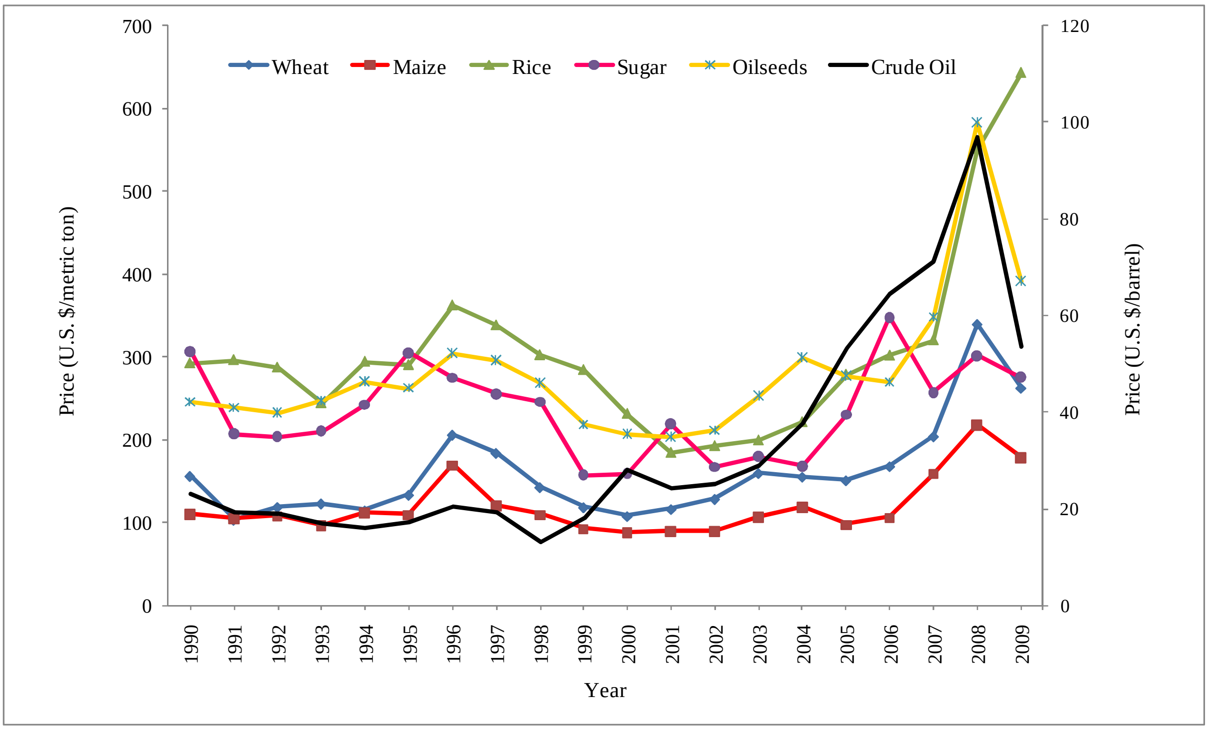

Figure 1.2: World Prices of Selected Commodities, 1990-2009

Sources: Data on wheat, maize, rice, sugar, and oilseeds are from OECD (2005) and OECD (2009) for 1990-2003 and 2004-2009, respectively (U.S. $/metric ton). Data on crude oil are from IMF (2009) (U.S. $/ barrel on right-hand scale of the Figure).

Schmidhuber (2006) notes that the more direct relationship between energy and agricultural commodity markets results in higher energy prices creating price floors for agricultural commodities when demand stemming from the energy sector is substantial, and agriculture-based feedstocks are competitive in the energy market. He suggests further that energy prices may also create price ceilings for agricultural feedstocks, depending on how quickly feedstock prices rise relative to energy prices and on their energy equivalents, particularly in the long-run. Hochman *et al*. (2008) add that the interdependence of food and energy markets could reduce price variability in agriculture, since biofuels not only provide additional demand for various agricultural commodities, raising average prices, but also cause the demand for these commodities to become relatively more elastic, thus reducing variability in (food) prices induced by weather and other random shocks. These authors also suggest that since the biofuel industry is prone to periods of boom and bust, driven primarily by food market volatility, biofuels may also serve to reduce energy price variability.

The Food and Agriculture Organization defines food security as a condition which exists "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO,1996: 4). This definition comprises four dimensions of food security: food availability, stability of food supplies, access, and utilization (i.e., people's ability to absorb nutrients) (Schmidhuber, 2006; Elobeid & Hart, 2007). Pingali *et al.* (2008) suggest that each of the first three dimensions above could potentially be affected by biofuel expansion, since biofuels affect the availability of food by competing directly for commodities and with productive resources; access to food is primarily determined by income and food price levels; and price volatility is the key determinant of the stability dimension.

In terms of the future outlook, Rosegrant *et al*. (2008) provide global predictions under three scenarios, referred to as the "baseline scenario," "biofuel expansion," and "drastic biofuel expansion." The first assumes that global biofuel production increases by one percent annually until 2010, and thereafter remains constant. The second is based on actual national biofuel expansion plans through 2020, although it assumes that U.S. and Brazilian growth will slow after 2010. The third assumes that global biofuel production is double that of the second scenario in 2015 and 2020. Compared to the baseline, the prices of maize, oilseeds, sugar, cassava, and wheat are estimated to be 26, 18, 12, 11, and 8 percent higher in the second scenario; and 72, 44, 27, 27, and 20 percent higher in the third scenario.

Rosegrant *et al*. (2008) also note that rapid biofuels expansion will likely have significant implications for international trade, particularly for the global trade balance of maize. For example, with the persistence of bioethanol expansion in the U.S. in 2006, Elobeid and Hart (2007) estimated that U.S. maize prices increased by approximately 60 percent, while world maize prices rose by greater than 50 percent. The significant increase in the area planted to maize reduced the plantings of other crops, most notably soybeans (Herndon, 2008; Senauer, 2008), and in so doing increased their prices (Senauer, 2008). Elobeid and Hart (2007) subsequently estimated that U.S. wheat and soybean prices increased by approximately 25 and eight percent respectively, and increased by 21 and seven percent, respectively, in the world market. Evidently, the U.S.'s dominance in these commodities has spillover effects in world markets.

There appears to be consensus, however, that the demand for biofuels accounts for only a portion of recent increases in food prices (Pingali *et al*., 2008; Rosegrant *et al*., 2008; Senauer, 2008; Tyner & Taheripour, 2008b; Harrison, 2009; Sexton *et al*., 2009; Skipper *et al*., 2009; Yang *et al*., 2009). For example, simulations by Sexton *et al*. (2009) suggest that biofuels are responsible for between 25 and 60 percent of recent maize price increases. Furthermore, these authors suggest that short-term trends such as low inventories, supply shocks, and monetary policy have also contributed significantly to food price inflation post 2006; for instance, they attribute the price spikes in rice and wheat to negative supply shocks from adverse weather in Russia, Australia, and India in the past few years. Senauer (2008) contends that speculation has almost certainly become a significant factor that has driven commodity prices even higher. Similar views are held by Escobar *et al*. (2008) and Harrison (2009). Nonetheless, higher prices of agricultural commodities that are used in the production of food ultimately translate into higher food prices. These higher commodity prices would benefit producers in both developed and developing countries through increased incomes (Elobeid & Hart, 2007; Pingali *et al*., 2008). Since food items constitute a significant proportion of the consumption bundle of relatively low-income earners, lower global supplies and relatively higher world food prices may have substantial adverse impacts on the purchasing power of the impoverished (Pingali *et al*., 2008). Therefore, rising commodity prices may have both positive and negative impacts on both developed and developing countries' economies.

Developing countries, particularly relatively low-income food-deficit countries, are typically net exporters of primary agricultural commodities, as well as being net importers of food. They are also often characterised by having relatively large numbers of poor, rural, food insecure, and undernourished populations (Elobeid & Hart, 2007). Subsequently, distributional considerations tend to suggest that these groups are most vulnerable to rising and volatile food prices and are, therefore, expected to be most adversely affected by increased biofuel production (Cassman & Liska, 2007; Elobeid & Hart, 2007; Pingali *et al*., 2008; Rosegrant *et al*., 2008), at least in the short-run (Cassman & Liska, 2007; Pingali *et al*., 2008).

Pingali *et al*. (2008), however, suggest that current fuel versus food debates tend to overlook that there could potentially be a positive supply response, even from small-scale agricultural systems. If biofuel demand increases the returns to unemployed or underemployed resources, such as land and labour, or alternatively encourages investment in productivity-enhancing technology, then biofuels serving as a new source of demand for agricultural commodities could actually assist in revitalising agriculture in developing countries, with potentially positive impacts for economic growth, poverty reduction, and food security. Similarly, Schmidhuber (2006) emphasises the benefits of increased producer prices and positive income effects, particularly in rural economies.

There appears to be consensus that expansion of maize-based bioethanol is likely to have the most significant impact on food prices. Harrison (2009) reports evidence indicating that higher maize prices contributed to inflated food prices for those items that depend on maize as a primary feed, such as eggs, poultry, pork, beef and milk. Elobeid and Hart (2007) postulate that countries where maize is the major food grain experience relatively larger increases in food basket costs than countries where wheat, sorghum and rice are the major food grains. Sub-Saharan Africa is heavily dependent on grain imports (Cassman & Liska, 2007), and is particularly vulnerable to price increases for various food commodities, reductions in the availability of calories, and subsequent increased levels of malnourishment (Mulugetta, 2008; Rosegrant *et al*., 2008). Accordingly, Elobeid and Hart (2007) estimate that the most substantial food price increases are likely to be seen in Sub-Saharan Africa and Latin America, where food baskets costs could increase by at least 10 percent for the period between 2007 and 2016.

Whether mandated through blending requirements or planned according to goals of energy self-sufficiency, increased farm income and/or rural economic activity, the continued expansion of biofuel production will undoubtedly have significant implications for the food and related sectors (Rosegrant *et al*., 2008). However, since biofuels have only made a relatively significant introduction into fuel markets in recent years, the full extent of these future impacts of potential shifts in agricultural commodity use on global food, feed and fibre markets are largely uncertain (Skipper *et al*., 2009). Senauer (2008) suggests that in addition to the future price of crude oil, these uncertainties essentially relate to whether countries reconsider their current policy actions, such as subsidies and mandates, that encourage the production of first generation biofuels; technological advancements in both enhancing crop yields, and the development of commercially viable second and even third generation biofuels; and whether or not serious efforts are made to mitigate global climate change.

Similarly, Pingali *et al*. (2008) suggest that growth in agricultural productivity is essential to prevent conflict between food and biofuels, and emphasise the importance of addressing constraints to technology adoption and market participation by the poorest developing countries. Cassman and Liska (2007) share a similar view, suggesting that net grain importing regions will be in a race against time to enhance agricultural productivity as food prices rise and there is less surplus for export and humanitarian aid. In this regard, Hochman *et al*. (2008) and McLaren (2008) stress the potential role of biotechnology in permitting greater per capita food production amid continued population growth and a diminishing agricultural land base. Similarly, Sexton *et al*. (2009) contend that a comparison of yield growth between commodities that have transgenic varieties and those that do not suggests that biotechnology has been an important driver of productivity growth in the past decade.

Hill *et al*. (2006) conclude that energy conservation and biofuels that are not food-based are likely to become increasingly more important in the long-term. Clearly policy choices will continue to play a significant role in years to come (Tyner & Taheripour, 2008b), and despite the lack of consensus of the impacts that biofuel expansion could have on food and related markets, Hochman *et al*. (2008) and Sexton *et al*. (2009) note that governments in both the U.S. and Britain started to review their biofuel policies in 2007 and 2008, in order to slow their rate of growth in favour of focusing on new biofuel technologies that are anticipated to compete less intensely with food production. Similarly, Yang *et al*. (2009) note that the general shortage in market supply and concerns related to food security resulted in the Chinese government placing a ban on expanding maize- and other grain-based biofuel production, in favour of promoting non-grain alternatives.

1.3 Biofuels and Sustainability

1.3.1 General Overview

Owen (2006: 207) defines externalities as "benefits or costs generated as an unintended by-product of an economic activity", and regards environmental externalities as benefits or costs that are evident through changes in the physical-biological environment. Of particular interest in the development and expansion of biofuel production are the proposed environmental benefits, including the potential reduction in emissions, such as greenhouse gases (Coyle, 2007). However, any potential direct environmental benefits from biofuels need to be weighed against potential indirect costs (Worldwatch Institute, 2007; Nelson & Robertson, 2008). Coyle (2007) estimates that 25 percent of manmade global carbon dioxide emissions are attributed to road transport. He notes further that global road transport has grown markedly in recent times, and is expected to continue to increase in the future, particularly in middle-income countries that are experiencing considerable economic growth, middle-class expansion, and urbanization.

Owen (2006) notes that the costs associated with climate change, such as flooding, changes in agriculture patterns and other effects, whilst undeniably important, are often difficult to determine with much certainty in practice. Agriculture's contribution to greenhouse gas emissions vary among countries, with substantial differences existing between developed and developing countries. The latter's agriculturally-based emissions are largely attributed to deforestation and land degradation; whilst developed countries agriculturally-based emissions stem from energy use, tillage practices, livestock feeding, and fertilizer applications (McCarl & Schneider, 2000).

Rajagopal and Zilberman (2007) note that biofuels are intensive in the use of inputs, which include land, water, crops, and fossil energy, all of which have an opportunity cost. Although non-renewable fossil fuels are utilised throughout the life cycle of biofuels as raw material for fertilizers, to power equipment used in planting and harvesting practices, and to transport both feedstock and final product, biofuels are generally regarded as being renewable in the sense that their primary feedstock can originate from numerous renewable biomass sources (Marshall, 2007). Reijnders (2006: 864) defines the sustainable use of biomass as "a type of use that can be continued indefinitely without an increase in negative impact due to pollution while maintaining natural resources and beneficial functions of living nature relevant to mankind over millions of years, the common lifespan of a mammalian species". Similarly, Marshall (2007) advocates that biofuels can be regarded as sustainable only if those feedstocks and fuels are cultivated, produced, and combusted in a manner that does not compromise the long-term health and productivity of air, soil, and water systems, or unbalance the social systems that are dependent on those resources.

Reijnders (2006) regards the following environmental aspects of modern bioenergy chains as crucial to sustainability: the impacts on stocks of natural resources (particularly soil, soil organic matter, soil nutrients, fossil fuels, and water); the mobilisation of elements and impacts on climate change; and the effect on biodiversity. However, two prominent themes have emerged from debates surrounding the sustainability of biofuels: concerns surrounding the carbon balances of biofuels, and apprehensions about the sustainability of feedstock production (Marshall, 2007). Underlying these are complex inter-linkages that give rise to trade-offs between environmental sustainability, overall economic gains, and welfare losses for the poorest individuals who are most vulnerable to global economic and environmental change (Rosegrant *et al.*, 2008), the magnitude of which are expected to rise with the increase in the global scale of biofuel production (Yang *et al.*, 2009). However, Marshall (2007) suggests that such debates invariably lead back to the question of how to identify and quantify the impacts of biofuel production and combustion, and ultimately how to incorporate these implications into policies that provide the necessary incentives for the evolution and adoption of truly environmentally friendly and sustainable feedstock and fuel technologies.

1.3.2 Carbon and Net Energy Balances

One of the most prominent arguments advocating an expansion of biofuel production is that they are more environmentally friendly than fossil fuels (Rajagopal & Zilberman, 2007; Worldwatch Institute, 2007). Hill *et al.* (2006) suggest that in order to be a viable alternative for fossil fuels, biofuels should have superior environmental benefits, be economically competitive, and be able to be produced in sufficient quantities to have a significant impact on energy demands, whilst simultaneously providing a net energy gain over the energy sources used to produce it. The ratio of energy generated to energy used in production is known as the net energy balance (Worldwatch Institute, 2007; Morrone *et al.*, 2009). Furthermore, Hill *et al.* (2006) note that determining whether alternative fuels provide net benefits over the fossil fuel they displace requires comprehensive evaluations of both direct and indirect inputs and outputs for their full production and use life cycles.

Life cycle analysis (LCA) is based upon a comprehensive accounting of all energy and material flows, both upstream and downstream, associated with a system or process (Owen, 2006). The Worldwatch Institute (2007: 163) suggest that the energy inputs for biofuels can be broadly classified as: (i) the agricultural energy necessary to cultivate and/or harvest the feedstock; (ii) the processing energy required to convert the feedstock into biofuels; and (iii) the transportation energy needed to deliver the feedstock to the refinery and deliver fuels to commercial depots. The first two categories, however, are typically the dominant energy uses in biofuel production. Importantly, Rajagopal and Zilberman (2007) caution that results of LCA are often only relevant in a specific geographic, temporal and technological context.

Hoekman (2009) suggests that although many LCA studies have considered – at least partially - the impacts of direct land use changes, they have generally not accounted for indirect land use changes, such as the clearing of forests to cultivate crops in order to satisfy food and/or feed requirements that have been disrupted by biofuel production. Furthermore, by-products have a significant bearing on the net energy and environmental benefits; however, there is uncertainty over the most suitable technique for the valuation of by-product credits in LCAs (Rajagopal & Zilberman, 2007). Despite these concerns, however, LCA has become an important decision-making tool used in evaluating alternative fuels, since it is particularly important to examine the fuel's life cycle systematically in terms of energy efficiencies, environmental impacts, and associated costs and benefits before implementing a fuel policy (Escobar *et al*., 2008; Hu *et al*., 2008). Carbon and net energy balances are common indicators used in LCAs (Rajagopal & Zilberman, 2007).

Biofuels are often been regarded as being carbon neutral, in that the carbon emitted through combustion replaces the carbon absorbed during the growing of the crop, whilst fossil fuels are considered to be overwhelmingly carbon positive (Reijnders, 2006; Coyle, 2007; Rajagopal & Zilberman, 2007; Schlegel & Kaphengst, 2007; Mathews, 2008). Recently, there has been considerable debate and often little consensus over the actual degree of carbon neutrality and associated energy balances achieved by biofuels (Mathews, 2008; Morrone *et al*., 2009), and estimates often vary substantially (Coyle, 2007). Gohin (2008) and Ovando and Caparrós (2009) concur, suggesting that the contribution of biofuels to greenhouse gas abatement efforts is highly controversial.

For example, using LCA, Hill *et al*. (2006) estimated that 93 and 25 percent more useable energy than the fossil energy required for its production was provided by soybean-based biodiesel and maize-based bioethanol, respectively. Furthermore, they found soybean-based biodiesel to be markedly more environmentally friendly than maize-based bioethanol, owing largely to lower agricultural inputs and more efficient conversion of feedstocks to fuel in the case of soybean-based biodiesel. By contrast, however, Pimentel and Patzek (2005) estimated that maize-based bioethanol and soybean-based biodiesel production required 29 and 27 percent more energy than the fuels produced, respectively. They suggest further that sunflower-based biodiesel required as much as 118 percent more energy than the resultant biodiesel contains, and also provide estimates for bioethanol produced from wood and switchgrass.

It should, however, be noted that the Pimentel and Patzek (2005) study is strongly criticised by both Wesseler (2007) and the Worldwatch Institute (2007). For example, Wesseler (2007) suggests that the energy balances for the different crops reported ignore opportunity costs. Taking these into account, Wesseler (2007) concludes that the biofuels resulting from maize, soybean, and sunflower have positive net energy balances, whilst the negative balances for wood and switchgrass are significantly reduced in comparison to the results reported by Pimentel and Patzek (2005). Moreover, the Worldwatch Institute (2007: 178) suggests that "they also include data that are outdated and do not represent the current agricultural and refining processes, and/or are poorly documented and thus cannot be fully evaluated".

Tiffany (2009) points out that the results of studies of this nature are highly dependent on their underlying assumptions, particularly those of feedstock yields. Coyle (2007), Frondel and Peters (2007), and the Worldwatch Institute (2007) conclude that most recent studies indicate that the net energy balances of biofuels are positive. However, the opposite view is held by Rajagopal and Zilberman (2007). There appears to be consensus that the net energy balances for soybean-based biodiesel and sugarcane-based bioethanol are more substantial than that of maize-based bioethanol (Coyle, 2007; Martinez-Gonzalez *et al.*, 2007; Morrone *et al.*, 2009; Tiffany, 2009)[2]. Hill *et al.* (2006) also advocate that biofuels would generally provide more substantial benefits if their feedstocks could be produced with relatively low agricultural inputs (i.e., less use of fertiliser, pesticides, and energy), on land with relatively low agricultural value, and required relatively low-input energy to convert the feedstocks to biofuel. Moreover, they suggest that future non-food feedstocks may perform even better in energetic, environmental, and economic criterion.

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[2] For a comprehensive review of past LCA, carbon and net energy balance studies, please see Pimentel and Patzek (2005), Hill *et al.* (2006), Rajagopal and Zilberman (2007) and the Worldwatch Institute (2007).

1.3.3 Land Use Effects and Implications for Water Quantity and Quality

Rajagopal and Zilberman (2007) criticise the popular literature that appears to focus largely on carbon and net energy balances when evaluating the environmental impacts of biofuels, while ignoring other indicators such as those related to human health, soil erosion, nutrient loading in rivers, biodiversity and the health of ecosystems. Although biofuel feedstocks vary widely by region, all require both land and water in some form. Tiffany (2009) suggests that the production of biofuels typically leaves a larger footprint in terms of land use than the production of numerous fossil fuel energy sources. De Fraiture *et al*. (2008) note that scarce land and water resources are already a significant constraint on agricultural production in many parts of the world. The amount of land required is a function of crop productivity (tons per hectare) and the conversion efficiency of the feedstock (biofuel yield per ton) (Marshall, 2007). Therefore, a continued global expansion of biofuel production, and subsequent price increases for numerous agricultural commodities, may have significant impacts on land use. In this regard, Nelson and Robertson (2008) and Rosegrant *et al*. (2008) suggest that higher crop prices could bring about two categories of land use changes with potentially adverse environmental consequences – increased cropping intensity and an expansion of cropping area.

Nelson and Robertson (2008) note that higher prices associated with crops used as biofuel feedstock augment the incentives for producers to intensify existing cultivation of those crops, and/or shift some areas from alternative crops to biofuel feedstock crops. For example, Susanto *et al*. (2008) provide statistical evidence of these potential significant changes in crop acreage favouring maize over cotton, soybeans, and wheat in the southern states of the U.S. as consequence to expanded bioethanol production. Similar analyses are provided by Tokgoz *et al*. (2008) and Wilson *et al*. (2008). Nelson and Robertson (2008) also suggest that higher prices typically make the use of purchased inputs more profitable, with increasing use of fertiliser and pesticides likely, and possibly more profitable use of mechanization and irrigation.

Potential environmental impacts associated with such intensive monocultures include ground and surface water contamination (e.g., eutrophication and eco-toxicity), further exploitation of scarce water supplies, increased greenhouse gas emissions through greater transportation of both inputs and outputs, and a loss of biodiversity (Schlegel & Kaphengst, 2007; Nelson & Robertson, 2008; Petrou & Pappis, 2009). Peters and Thielmann (2008) suggest that the severity of these problems tend to be amplified in developing countries. Similarly, Rosegrant *et al*. (2008) contend that for land-scarce regions that are unable to adjust to increased biofuel feedstock demand by means of expanding the existing land area under a particular crop, or alternatively the substitution away from one crop in favour of another, intensification of agricultural practices may be the only available alternative. Müller *et al*. (2008) add that intensive monoculture practices may result in greater vulnerability of the agricultural sector to abnormal crop growing conditions, such as extreme weather patterns, pests and diseases.

However, the extent of such effects depends on which biofuel crops see the most significant expansion (Nelson & Robertson, 2008; Yang *et al*., 2009). For example, Hill *et al*. (2006) suggest that data on agrichemical inputs for maize and soybeans, and on efficiencies of net energy production from the respective feedstocks, reveal that soybean-based biodiesel uses, per unit of energy gained, approximately one, 8.3, and 13 percent of the nitrogen, phosphorous, and pesticide (by weight) used for maize-based bioethanol. Moreover, these authors suggest that the pesticides used in maize production are more environmentally harmful and persistent than those used in soybean production. Subsequently, concerns over both water quality and quantity are more severe in scenarios where increased biofuel production stems primarily from maize (Hoekman, 2009).

The Worldwatch Institute (2007: 142) contends that an expansion of biofuel production and trade is beneficial from a cost and environmental perspective “only if it is cultivated on already established agricultural or set-aside lands, or on degraded lands poorly suited for traditional agriculture”. Similarly, Sexton *et al*. (2009: 139) suggest that a sustainable biofuel future hinges critically on the capacity of agriculture to satisfy demand for energy crops without drawing “natural lands” (e.g., rainforests) into agricultural production, since natural lands act as carbon sinks, absorbing greenhouse gases and storing them in the ground and in biomass. However, in addition to the more intensive use of existing cropland, conversion of natural land to agricultural uses will likely occur with continued biofuel expansion (Nelson & Robertson, 2008). A similar view is held by Marshall (2007), who contends that it would be naive to assume that the land necessary for increased biofuel feedstock production will be drawn solely from the pool of available marginal land.

Subsequently, competition for scarce land resources among crops will likely increase pressure for deforestation (Müller *et al*., 2008; Petrou & Pappis, 2009), particularly in developing nations, resulting in substantial losses of natural biodiversity (Müller *et al*., 2008).

For example, Gurgel *et al*. (2007) suggest that European blending requirements and the demand for biodiesel in particular, have been linked to expanding oil palm plantations and deforestation in countries such as Malaysia, Indonesia, and Thailand. Nelson and Robertson (2008), however, suggest that land use changes are possible in any location where increased prices for agricultural commodities result in previously unprofitable agricultural practices becoming profitable. In this regard, Marshall (2007) notes that although the value of habitat and carbon sequestration services is seldom internalised in either public or private decisions resulting in land use change, quantifying the loss of such services is essential to gain a clear perspective of the environmental and economic costs of continued biofuel feedstock production and expansion. However, in practice this is often difficult to achieve.

Rosegrant *et al*. (2008) suggest possible land use changes, in the form of shifting land from existing crop production toward a dedicated biofuel feedstock crop, have the potential to alter irrigation water use and subsequently local water availability. Worldwide, agriculture is already the main consumer of fresh water, accounting for approximately 75 percent of current water use (Wallace, 2000). Furthermore, water is a crucial factor of production permitting the intensification of agricultural practices (Rosegrant *et al*., 2008). Therefore, the Worldwatch Institute (2007) and Nelson and Robertson (2008) note that an expansion of biofuel processing facilities will likely result in an increased demand for fresh water as well as increased waste products. Both are expected to have significant environmental impacts, but are often difficult to quantify.

Russi (2008) suggests that both the quantity of available water and its quality could potentially be adversely affected by a continued biofuel expansion. In this regard, Nelson and Robertson (2008) contend that water quality is most likely to be affected by changes in intensity of crop production, since increased fertiliser and pesticide applications increase the likelihood of these chemicals reaching ground and/or surface water bodies. By comparison, they suggest that water quantity measures (such as stream flow volume and variability) are expected to be affected by land use changes, which may alter root structure and cover (both of which influence water flow through the system). Rosegrant *et al*. (2008), however, suggest that the continued expansion of biofuels would only increase the stress on regional water supplies marginally, although the impact for some individual countries, particularly China and India, could be highly significant (de Fraiture *et al*., 2008; Müller *et al*., 2008). The Worldwatch Institute (2007) conclude that careful crop selection and management practices are important factors which may mitigate the effects of biofuel expansion on water. However, they point out that problems with water availability and use may represent an important limiting factor on the future production of biofuels.

1.3.4 Sustainability Standards and Certification Schemes for Biofuels

Buchholz *et al*. (2009) note that the use of biomass does not automatically imply that its production, conversion, and use are sustainable. Thus, in light of an increasing amount of debate and controversy surrounding the environmental footprint of biofuels, particularly surrounding deforestation and the competition of biofuels with food and feed, the question of how to ensure that biofuels are produced in a sustainable manner has stimulated even more intense deliberations (Lewandowski & Faaij, 2006; Mathews, 2008). For example, Hoekman (2009) suggests that extreme care must be exercised to ensure that the continued shift towards and expansion of biofuels will be both sustainable and affordable, with minimal adverse environmental consequences. Similarly, Plieninger and Bens (2008) suggest that replacing fossil fuels with biofuels is insufficient, as sustainability cannot be achieved without dramatic increases in energy conservation and efficiency.

Thus, it has been suggested that some form of coordination of policies at a global level is necessary to address these concerns (Rajagopal & Zilberman, 2007). Establishing sustainability standards and certification schemes are possible strategies that can aid in ensuring that bioenergy crops are produced in a sustainable manner (Schlegel & Kaphengst, 2007; Garcez & Vianna, 2009). Accordingly, in order to advance the development of biofuels in a sustainable direction, a number of European and international organisations have begun to identify and establish sets of technical specifications for biofuel production (Marshall, 2007; Schlegel & Kaphengst, 2007; Gordon, 2008; Mathews, 2008), and to advocate for their application in both national and international policy (Marshall, 2007).

A number of studies have analysed and outlined crucial issues for the development of sustainability standards and certification schemes (Schlegel & Kaphengst, 2007; Garcez & Vianna, 2009). Although Buchholz *et al*. (2009) note that no clear consensus has been established on what experts regard as critical indicators of sustainability, Elghali *et al*. (2007: 6075) suggest that the criteria typically recognised as representing tests for sustainability include: economic viability in the market and fiscal framework within which the supply chain operates; environmental performance, including, but not limited to, low carbon dioxide emissions over the complete fuel life cycle; and social acceptability, with the benefits of using biomass recognised as surpassing any adverse social impacts. An extensive evaluation of possible certification criteria and indicator sets for sustainable biomass trade are provided by Lewandowski and Faaij (2006).

Schlegel and Kaphengst (2007) suggest that a significant instrument to enforce certification schemes of this nature could be the exclusion of biofuels that fail to meet the sustainability criteria from contributing towards national biofuel targets, and additionally being ineligible for benefits such as tax exemptions and similar types of financial support. It should, however, be noted that the creation of sustainability standards and certification schemes may pose obstacles to international trade, since there are restrictions on the types of standards that can be imposed on international trade agreements whilst still remaining compliant with the World Trade Organisation’s regulations (Marshall, 2007; Schlegel & Kaphengst, 2007; Gordon, 2008).

In addition to potential trade obstacles, Schlegel & Kaphengst (2007: 9) identify the following issues with regard to the design and implementation of sustainability standards and certification schemes:

- Availability of certified feedstocks.
- Current limited focus on biofuels.
- Inconsistent definitions of sustainability.
- Limited stakeholder participation.
- No exclusion of unsustainable practices by the introduction of voluntary standards.
- Macro-level impacts.

Buchholz *et al*. (2009) conclude that international debate and search for sustainability criteria and frameworks are likely to be ongoing, and suggest further that a single fixed set of criteria would probably not be advisable for all bioenergy systems. The next chapter provides a review of global biofuel policies.

CHAPTER 2: A REVIEW OF BIOFUEL POLICY ALTERNATIVES

Global biofuel production has risen substantially in recent years, principally driven by government support for these industries. The stated motivations for these initiatives are numerous and have varied over time. This chapter presents a review of some important economic aspects of the most widely used biofuel and related policies around the world, and provides some theoretical and empirical evidence of these initiatives. The SA government's current biofuel policy stance is also evaluated, with concerns expressed over the fact that the commitment to the Renewable Energy White Paper is not binding. Nevertheless, continued technological advancements, infrastructure development, and government interventions will be central to the future developments of biofuel industries, both locally and globally.

2.1 General Overview

Rajagopal and Zilberman (2007) point out that there has been an extensive history of dependence of alternative energy technologies on sustained governmental support in order to be competitive with fossil fuels in the marketplace. Biofuels are no exception, with government intervention in bioethanol markets dating back to 1978 in the United States (U.S.) (Gardner, 2007; Tyner, 2007; Tyner & Taheripour, 2007, 2008b), in the form of subsidies, federally-funded research, and quantity mandates (Khanna *et al.*, 2008). Similarly, Brazil, now a well-established producer and consumer of bioethanol, promoted the development of its bioethanol industry through the National Alcohol Program (PROALCOOL) which was launched during the mid-1970s (Elobeid & Hart, 2007; Elobeid & Tokgoz, 2008). Sustained governmental support, therefore, has undoubtedly been an essential feature of the development of the biofuel industries in many of the present global market leaders in biofuel production (Coyle, 2007; Worldwatch Institute, 2007; Meyer *et al.*, 2008), particularly in the U.S., Brazil and European Union (EU), where biofuel production has been most significant (Coyle, 2007; Worldwatch Institute, 2007).

The stated motivations for these legislative initiatives are numerous and have varied over time (Tyner, 2007; Worldwatch Institute, 2007). Among the most prominent of these are to address broad societal objectives, including concerns over energy security, goals to improve environmental quality, decreased traffic congestion, reductions in the tax costs of farm subsidy programs, improving farm incomes and enhancing rural economic development

(Coyle, 2007; Rajagopal & Zilberman, 2007; Tyner & Taheripour, 2007; Worldwatch Institute, 2007; Khanna *et al*., 2008; de Gorter & Just, 2009a, 2009b).

Furthermore, Coyle (2007) suggests that governments tend to introduce supports to assist new and developing biofuel ventures to overcome both cost and scale disadvantages, as well as combating the inherent volatility in profits. This is essentially the "infant industry" justification for the use of subsidies. Martinez-Gonzalez *et al*. (2007) contend that since fossil fuel production is typically more price-competitive than the production of biofuels, government intervention is necessary in order to compensate for this gap in price competitiveness. This is attributed to the fact that under current available technologies, the costs associated with producing crops and converting them to biofuels are too high for them to compete with fossil fuels on a commercial basis without active governmental support to promote both their development and use (FAO, 2008). U.S. bioethanol policy in particular has stimulated considerable debate as to its effectiveness in solving the host of policy issues listed above (de Gorter & Just, 2008a, 2008b). It should also be noted that many countries intervene in both agricultural and energy markets (FAO, 2008).

The literature surrounding the potential implications of biofuel policies is still in its developmental stages (Rajagopal & Zilberman, 2007; Worldwatch Institute, 2007), with studies typically being either theoretical or simulation based, and usually concentrating on predicting the impact of reaching a particular biofuel target on a relatively small set of indicators (Rajagopal & Zilberman, 2007). Similarly, Banse *et al*. (2008) criticise that many models do not explicitly account for oil prices, restrict the policy measures to biofuel blend mandates, and often lack international trade considerations of biofuels. Rajagopal and Zilberman (2007) note further that there is a distinct lack of econometric evaluations of biofuel policies, and attribute this to problems such as relatively short time-series data, and difficulties in determining causality and isolating the effects of individual policies. In a similar regard, Gardner (2007) notes that supply and demand parameters for bioethanol are difficult to estimate with precision since only a limited time period of market data are available, and these are under favourable structural conditions for bioethanol use (i.e., technology, institutions, and regulations). A similar view is held by Elobeid and Tokgoz (2008).

The rapid growth of biofuel production in recent years has stimulated considerable and growing deliberations over how policy changes will continue to influence this emerging industry and associated spillover effects into other markets (Elobeid & Tokgoz, 2008). The importance of the correct set of biofuel policies has been noted by numerous authors, with the vast majority of published applications focusing specifically on the U.S. bioethanol industry (Gardner & Tyner, 2007; Meyer *et al.*, 2008), very recent examples of which include de Gorter and Just (2009a, 2009b) and de Gorter *et al.* (2009). Similarly, de Gorter and Just (2008a) note that the potential misalignment of policy effects and stated objectives can pose serious difficulties for policy analysis, and emphasise the importance of the fundamental underlying economics of these policies. While numerous policy tools exist that could be used to achieve desired objectives, the cost effectiveness as well as the distributional implications of each will vary, creating both winners and losers among economic agents (Rajagopal & Zilberman, 2007). Accordingly, Parcell and Westhoff (2006) suggest that an understanding of how the economic costs and benefits from biofuel production are distributed is valuable when assessing future expansion of biofuel production, and establishing future biofuel policy. The primary objective of this chapter, however, is to provide a comprehensive compilation of economic literature surrounding the global biofuel policy spectrum.

2.2 The Rationale for Government Intervention in Biofuel Markets

Rajagopal and Zilberman (2007) suggest that normative welfare analyses and political economic theory are the two most prominent methods used to explain the rationale for government intervention. The welfare maximisation argument, or alternatively the market failure hypothesis, is consistent with the view that government intervention can enhance allocative efficiency (Pasour & Rucker, 2005). Khanna *et al.* (2008) suggest that economists are typically in favour of government intervention in the market when there are market failures, such as those resulting from environmental externalities. Accordingly, Tyner (2007) contends that biofuels present two forms of market failures, the first being that markets do not internalise the costs of energy security, and the second relating to environmental impacts of energy use such as greenhouse gas emissions, which in turn are linked to concerns over global warming.

Additionally, Rajagopal and Zilberman (2007) suggest that market failure relating to biofuels may arise due to: (i) the generation of public goods, since research and development investments relating to the production and processing of biofuels may lead to knowledge spillovers, which are public goods, and subsequently result in an underinvestment by the private sector; (ii) protection of infant industries, that are given special incentives and support to develop both skills and capacity; and (iii) uncertainty, where investors may be inherently risk averse while government may be risk neutral. Tyner (2007) postulates that in order to correct market failures, government could introduce an additional, and substantially higher, tax on fossil fuels, subsidise alternatives to fossil fuels, or impose fuel standards that stipulate a minimum blend percentage of domestically produced alternatives to fossil fuels. Since the practicalities of an imposition of an increased tax regime are relatively complex (Owen, 2006), and are probably unlikely in many political contexts (Tyner, 2007), the focus of this article will primarily be on subsidies to alternative fuels and alternative fuel standards.

The second means to explain the rationale for policy, as suggested by Rajagopal and Zilberman (2007), is from the political economic standpoint which proposes that public intervention is merely a demonstration of the rent-seeking behaviour of politicians, voters, lobbyists and bureaucrats. Environmental parties support biofuel use as a means of combating greenhouse gases; venture capitalists, biofuel plant owners, manufacturers of biofuel processing equipment and plant facilities, crop farmers and their supporting agribusinesses all have large vested interests to protect, and potentially have a lot to gain from, a continued biofuel expansion and government protection (Herndon, 2008). With so many entrenched market participants, the removal of existing governmental support from biofuel markets could prove to be politically unpopular.

Rajagopal and Zilberman (2007) suggest that the market failure hypothesis, and associated social welfare arguments, implicitly assign equal weights for different economic groups. In this regard, however, Pasour and Rucker (2005) contend that the view that government initiatives can enhance efficiency is subjective and, therefore, economically indefensible as it would require making both value judgements and interpersonal utility comparisons. In contrast, Rajagopal and Zilberman (2007) suggest that the political economic approach typically assigns different weights to different economic groups. Subsequently, these authors advocate that the current set of biofuel related policies appear to be designed to benefit political constituencies, rather than maximise welfare and/or environmental objectives. Similarly, de Gorter *et al*. (2009) propose that policies in the form of biofuel tax credits, biofuel import tariffs, and production subsidies exist primarily due to non-economic objectives.

Rajagopal and Zilberman (2007) conclude that irrespective of the underlying motivations for public intervention in biofuel markets, the existence of market failures in energy markets is indisputable; and the goal of an effective policy should be to fully internalise any externalities, whilst paying due consideration to distributional effects. Owen (2006) suggests that the internalisation of externalities is likely to result in an increase in the cost of power generation from the combustion of fossil fuels, and, therefore, a relative improvement in the competitive position of an increasing number of renewable energy technologies. Finally, Hochman *et al*. (2008) emphasise the need for government biofuel policy to account for interactions between farm policy and energy policy, since agricultural commodity and energy markets have converged.

2.3 The Biofuel Policy Spectrum and Related Implications

A wide variety of policy tools are available for government intervention in biofuel markets, most of which are intended to encourage domestic production and stimulate demand for biofuels (Fridfinnson & Rude, 2009). Moreover, biofuel development is affected by numerous national policies in multiple sectors – including agriculture, energy, transport, environment, trade, and broader policies influencing the overall "enabling environment" for business and investments (FAO, 2008: 27). However, no individual policy provides an optimum solution under all circumstances. For example, Lichtenberg and Zilberman (1986) note that the efficiency of any policy approach is dependent on the presence of pre-existing market distortions (possibly resulting from other forms of governmental intervention), as these distortions may have considerable effects on the allocation of scarce resources. Rajagopal and Zilberman (2007) add further that the actual choice of biofuel policy will likely be dependent on various factors such as government budgets, resource availability, the accessibility and cost of information, transaction costs, and political economic considerations. Figure 2.1 exhibits the various points along the biofuel supply chain where direct and indirect policy measures can provide support for the biofuel industry.

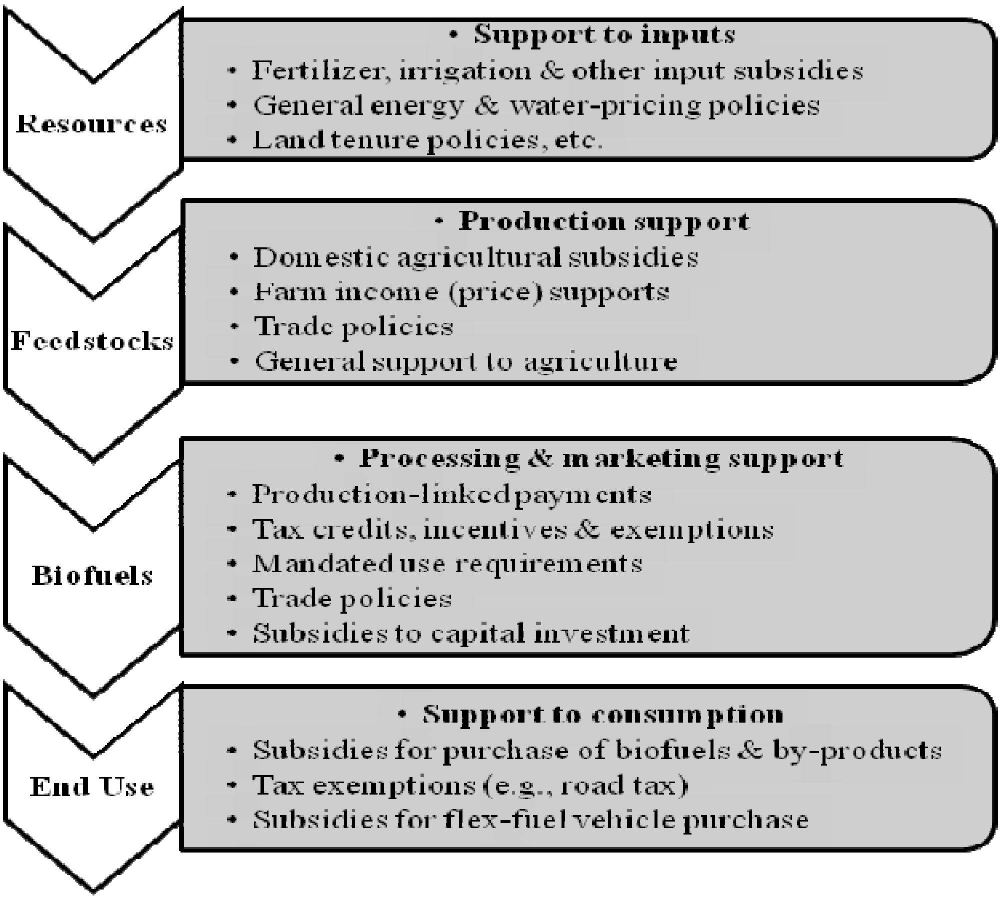

Figure 2.1: Government Support at Different Points in the Biofuel Supply Chain

Source: Adapted from FAO (2008:28).

Kojima *et al.* (2007: 45) surmise that biofuel related policies around the world include the following:

- Fuel excise tax reductions or exemptions relative to taxes on fossil fuel products.
- Mandatory blending and/or consumption requirements.
- Import tariffs and/or quotas on biofuels, used in conjunction with preferential adjustments of tariffs and quotas for particular countries – primarily aimed at restricting access to benefits from biofuel promotion policies and favoured countries.
- Price supports intended to stimulate and increase biofuel production.
- Producer payments and tax credits linked to production.

- Investment incentives (e.g., grants, loans, and loan guarantees), and tax-related incentives (e.g., tax holidays, accelerated depreciation, and tax reductions).
- Grants and funding for research and development aimed at increasing the supply of biofuels.
- Downstream subsidies for vehicles designed to work using high-blend biofuels, and for storage facilities targeted at the infrastructural development of fuel production and consumption.

The following sections evaluate the important characteristics of some widely used biofuel and related policies, of which excise tax credits, renewable fuel standards and mandatory blends appear to be most widely utilised. The implications that these policies have for economic welfare and, to a lesser extent, the environment are also evaluated.

2.3.1 Excise Tax Credit for Biofuels

Most countries around the world levy a tax on the use of petroleum and diesel (Rajagopal & Zilberman, 2007). De Gorter and Just (2009b: 738) define a biofuel tax credit as "a reduction (or elimination) of the fuel tax charged on sales based on the biofuel content". A fuel tax reduction for biofuels, therefore, attempts to decrease the cost of biofuel relative to petroleum and/or diesel (Rajagopal & Zilberman, 2007). There appears to be consensus that reductions in fuel excise tax are currently the most direct and extensively used policy instrument to assist biofuels to compete with their fossil fuel counterparts (Kojima *et al*., 2007; Rajagopal & Zilberman, 2007; de Gorter & Just, 2009a). According to de Gorter and Just (2009a), exempted or reduced biofuel excise taxes cover at least 65 percent of total world consumption; and are known to be in effect in Argentina, Australia, Brazil, Canada, China, Columbia, EU, Ghana, Honduras, India, Indonesia, Japan, Paraguay, Philippines, South Africa, Switzerland, Thailand, Uruguay, and the U.S. (DME, 2006, 2007; Kojima *et al*., 2007; Rajagopal & Zilberman, 2007; de Gorter & Just, 2009a). However, the exact nature of these biofuel tax policies varies widely across countries (Rajagopal & Zilberman, 2007). Given the wide use of this policy instrument de Gorter and Just (2009a) emphasise the importance of understanding the potential effects of such a policy on the markets for agricultural commodities, biofuels, fossil fuels, as well as the potential implications for economic welfare.

There appears to be consensus that a biofuel tax credit alone essentially serves as a subsidy to biofuel producers (Rajagopal & Zilberman, 2007; de Gorter & Just, 2008a, 2008b), some of which may be passed on to the farmer (Rajagopal & Zilberman, 2007). De Gorter and Just (2008b: 2) show that a "tax credit alone increases the market price of ethanol above the gasoline price by the level of the tax"; and serves as a taxpayer transfer to both domestic and foreign biofuel producers. These authors further note that fuel consumers only indirectly benefit if oil prices decline with an increased supply of biofuels through the reduction in the average price of fuel. Thus, total fuel consumption may increase using this policy alternative. Schmitz *et al*. (2007) note that even a small decrease in the price of fuel translates into a large consumer gain because of the significant volume of fuel consumed. De Gorter & Just (2009a), however, suggest that the welfare effects of a tax credit depends on whether a given country is a large country importer or exporter in either the agricultural commodity used for biofuel production or fuel.

Biofuel excise tax credits may have adverse implications for government revenues, and the ability to use this policy instrument depend critically on both the presence and level of excise taxes levied on petroleum fuels (Kojima *et al*., 2007; Rajagopal & Zilberman, 2007). Kojima *et al*. (2007) suggest that in countries where fuel taxes are relatively high, as they are in place primarily as a means to generate government revenue, a reduction in fuel taxes would likely have adverse affects on the fiscal situation. In this regard, Peters & Thielmann (2008) estimate that South Africa, among other countries, where between 20 and 25 percent of total tax income originates from fuel taxation, could potentially lose in excess of two percent of their national tax revenue if tax exempted biofuels were to displace 10 percent of conventional fuels. Interestingly, Kojima *et al*. (2007) note that the tax rate levied on diesel is often comparatively lower than that of petroleum.

Tax subsidies are clearly effective in stimulating the production of biofuels, but fixed or unconditional tax subsidies have the risk of potentially transferring significant amounts of income to producers, particularly in the presence of high crude oil prices (Rajagopal & Zilberman, 2007; Tyner & Taheripour, 2008b). Tyner and Taheripour (2008b) highlight the possibility of introducing a variable biofuel subsidy that increases incrementally with corresponding decreases in the crude oil price. They estimated that under this regime biofuel production was markedly higher than under the fixed subsidy at relatively low crude oil prices. Similarly, Tyner and Taheripour (2007) analyse the possibility of implementing a two-part subsidy with a national security component (based on the energy content of the renewable fuel), and a component linked to the level of greenhouse gas emission reductions of the fuel. Rajagopal and Zilberman (2007: 61) conclude that tax credits, which do not vary with changes in the crude oil price and do not have caps on production levels or “sunset clauses”, may result in a marked increase in the subsidy cost in the event that there is a structural break causing substantially lower oil prices or, alternatively, a large increase in biofuel production.

2.3.2 Renewable Fuel Standards and Mandatory Blending

While taxes and subsidies are essentially incentive-based approaches, numerous national and state governments exert a more direct control over fuel markets by way of renewable fuel standards and mandatory blending requirements for biofuels (Rajagopal & Zilberman, 2007). Quantitative targets have typically been key drivers in the growth and development of most modern bioenergy systems (FAO, 2008). Thus, many governments around the world now require that a minimum percentage of transportation fuels sold to comprise of biofuels (de Gorter & Just, 2009b). The exact nature of this requirement differs around the world with respect to the extent to which it is considered mandatory, the phase-in period, the amount or blend percentage mandated, and whether a national or regional strategy is implemented (Coyle, 2007). Winkler (2005) contends that governments’ primary role should be to establish a quantitative target, and let the emerging renewable industry establish the most cost-effective way of meeting this objective.

Renewable fuel standards typically stipulate that the industry must acquire a certain percentage of its fuel from alternative domestic resources (Eidman, 2007; Tyner & Taheripour, 2007). These authors also suggest that the industry is required to purchase these alternative fuels irrespective of their cost in the market. As a result, the majority of these cost changes are passed on to consumers, by way of either cheaper or more expensive fuel at the pump. Therefore, unlike an excise tax credit, the effect of regulating the relative market shares by way of direct controls, such as mandatory blending policies and renewable fuel standards, are typically to increase the consumer price of fuel (Rajagopal & Zilberman, 2007; Banse *et al*., 2008; de Gorter & Just, 2008a). The final fuel cost to the consumer is, therefore, dependent on the cost of the alternative fuel (Tyner & Taheripour, 2007).

Interestingly, de Gorter & Just (2009b) indicate that, with a fixed price of fuel, mandates increase the consumer price of fuel, which necessarily results in reduced fuel consumption compared to a biofuel tax credit that generates an equivalent level of biofuel consumption. However, with endogenous fuel prices they show that it is possible for the consumer price of fuel to decline under a mandate, depending on the relative supply elasticities of bioethanol and fuel. Rajagopal & Zilberman (2007), however, note that from the regulatory institution's perspective, mandatory blending requirements are revenue neutral, while producer surplus increases and consumer surpluses decrease. Thus, Tyner & Taheripour (2008a) surmise that a binding renewable fuel standard imposes an implicit tax on fuel consumption (through higher prices at the pump) and provides an implicit subsidy for biofuel producers.

Banse *et al*. (2008) contend that mandatory blending policies result in an increased demand for biofuel feedstock which raises their prices relative to the crude oil price, and subsequently merely serve to augment the challenge of making biofuels competitive. Rajagopal and Zilberman (2007) and Tyner and Taheripour (2008b) conclude that while renewable fuel standards and mandatory blends are effective in stimulating the production of biofuels, they may be very inefficient in the presence of low crude oil prices.

2.3.3 Agricultural and Trade Policies

The active role governments play in allocating scarce resources between agriculture and the rest of the economy is indisputable (de Gorter & Swinnen, 2002). The majority of feedstock for the production of biofuels will likely come from the agricultural and forestry sectors (Walsh *et al*., 2007). Since feedstock accounts for a significant proportion of biofuel production costs (Haas *et al*., 2006; Rajagopal & Zilberman, 2007; You *et al*., 2008; Petrou & Pappis, 2009), agricultural and trade policies that influence the supply, demand, and prices of various agricultural commodities can, therefore, be important determinants of biofuel economics (Rajagopal & Zilberman, 2007).

The stated objectives of agricultural policy are varied and typically include self sufficiency, balance of trade (payments), farm income and employment targets, secure supplies and low prices to consumers, as well as the stability of farm incomes, supplies, and prices (Winters, 1989). In contrast to energy policies which have relied heavily on tax subsidies and mandates, agricultural policies have focused on either promoting or controlling product supply, through price supports, land-use acts, or regulation of import and export levels (Rajagopal & Zilberman, 2007). Historically, agricultural policies in industrial countries have protected domestic producers from imports from relatively lower-cost foreign producers, and in so doing transferring income to domestic farmers, while agricultural policies in developing countries have typically taxed exports to generate government revenue (de Gorter & Swinnen, 2002; Karp & Perloff, 2002; Kojima *et al*., 2007), and/or provide food for domestic consumers at relatively lower prices (de Gorter & Swinnen, 2002).

Pasour and Rucker (2005) demonstrate that price supports alone stimulate production. However, they invariably lead to surpluses and net costs to taxpayers, in the form of acquisition and possibly storage costs (these, however, do not include the deadweight and other opportunity costs associated with overproduction, such as a misallocation of scarce resources and reduced domestic consumption of the commodity; or the taxes necessary to run the program), thereby creating an incentive for further government intervention in the market through programs that regulate supply. Perloff (2007: 277) defines deadweight loss as the net reduction in social welfare from a loss of surplus by one economic group that is not offset by a gain to another group from an action that changes a market equilibrium. Pasour and Rucker (2005) suggest further that product supply can be reduced by means of either restricting input use (particularly land), or by regulating output directly. To this end, these authors note that acreage allotments and marketing quotas have been used extensively in U.S. farm price-support initiatives.

Prominent domestic agricultural policies in developed countries also include deficiency payments and other forms of direct producer subsidies (Karp & Perloff, 2002). Rajagopal and Zilberman (2007) suggest that price supports that are used in conjunction with deficiency payments have assisted in increasing production and lower market prices of commodities. In the U.S., government uses the deficiency payment method to support farmers of wheat, cotton, rice, and feed grains (Pasour & Rucker, 2005). The deficiency payment is the difference between a target price and the market price or loan rate, depending on which difference is smaller (Rajagopal & Zilberman, 2007). Tomek and Robinson (2003) note that this form of intervention can essentially subsidize both production and consumption, since producers receive above market equilibrium prices and consumers benefit from below market equilibrium prices. Rajagopal and Zilberman (2007) contend further that the effects of deficiency payments in biofuel markets are to reduce the cost of biofuel feedstocks, and subsequently the costs of biofuels and their by-products.

Trade policy has an extensive history as an important field of study in agricultural economics (Sumner & Tangermann, 2002). Government intervention in agricultural sectors in both developed and developing nations have created significant distortions in international markets over the years, with explicit trade interventions typically including an assortment of tariffs, quotas, export subsidies, and non-tariff barriers (Karp & Perloff, 2002). With specific reference to biofuel market intervention, Rajagopal and Zilberman (2007) note that governments around the world have imposed several forms of restrictions on the trade of both feedstock and biofuels; prominent examples of which include import tariffs, quotas, and export taxes, with preferential waivers for selected countries in some cases (see Appendix A).

The predominant effects of import tariffs and quotas are to provide protection for domestic producers (Tomek & Robinson, 2003), as well as restricting benefits to selected countries (Kojima *et al*., 2007). Consumers, however, are unambiguously harmed by these policy measures, whilst governments generate revenue from import tariffs, and possibly quotas, depending on the method of allocation (Tomek & Robinson, 2003). Export taxes, in contrast, may be implemented to promote the export of value-added finished products rather than raw materials (e.g., promoting the export of biofuel rather than feedstock – see Argentina's policies in Appendix A) (Rajagopal & Zilberman, 2007). In general, however, there has been a global shift towards the removal of barriers to trade in recent times. Accordingly, Rajagopal and Zilberman (2007) suggest that trade liberalisation in biofuel markets should serve to increase competition and lead to an improvement in average efficiency of production, ultimately translating into greater global welfare in the long-run.

Agricultural policies undoubtedly have had significant implications for both agricultural trade and the geographic patterns of agricultural production at the international level and are, therefore, expected to have similar influences on the production of biofuels (FAO, 2008). For a comprehensive review of the economic costs, benefits and shortcomings of the above, and other, agricultural policies please refer to Pasour and Rucker (2005), while an extensive review of current biofuel trade policies around the world is contained in Kojima *et al*. (2007).

2.3.4 Other Biofuel-Related Policy Initiatives

There is evidently a wealth of available forms of government intervention in biofuel and related markets, the most prominent of which have already been discussed at some length. A brief overview of energy and carbon taxes is given by Rajagopal and Zilberman (2007); however, these policies do not appear to have been adopted widely to date, and are often regarded as being politically unpopular alternatives. Rajagopal and Zilberman (2007) note further that taxes increase the price of fuel (similar to the effects of fuel standards and blend mandates) and generate government revenue. Their distributional effects to producers and consumers, however, depend on the price elasticity of demand - Rajagopal and Zilberman (2007) suggest that in the event that demand is relatively price inelastic, producers pass the tax on to consumers.

Kojima *et al.* (2007) indicate that investment incentives (e.g., grants, loans and loan guarantees), and tax-related incentives (e.g., tax holidays, accelerated depreciation, and tax reductions) are commonplace in biofuel and related markets around the world. Rajagopal and Zilberman (2007), however, note that policies such as trading mechanisms, biofuel certification systems, and compensation schemes such as payments for environmental services are yet to become well established in the context of biofuels. For example, the need to ensure that biofuels are produced in a sustainable manner has become increasingly controversial; and it has been suggested that establishing sustainability standards and certification schemes are possible strategies that could aid in ensuring that bioenergy crops are produced in a sustainable way (Schlegel & Kaphengst, 2007; Garcez & Vianna, 2009) (refer to Chapter 1 for more detail).

Research and development in bioenergy has typically been aimed at establishing technologies that enhance conversion efficiency, identifying sustainable feedstocks, and, increasingly, to developing cost-effective conversion methods for second and third generation biofuels (Rajagopal & Zilberman, 2007; FAO, 2008). Due to problems associated with knowledge spillovers (e.g., inventors may have difficulties in fully internalising the benefits of their innovations) it is often desirable for government to provide support for research and development (Rajagopal & Zilberman, 2007). Subsequently, this form of intervention is not uncommon in biofuel-producing countries around the world (Rajagopal & Zilberman, 2007; FAO, 2008). An extensive history of, and explanations for, public funding in agricultural research and development is given by de Gorter and Swinnen (2002).

Flex-fuel vehicles, which are designed to use higher-percentage blends of biofuels than ordinary vehicles, are also actively promoted by many governments around the world; for example, by directly reducing registration fees, providing tax credits (e.g., on road taxes), and indirectly through energy-efficiency credits to vehicle manufacturers (Kojima *et al*., 2007; Rajagopal & Zilberman, 2007; FAO, 2008). State and federal policies in the U.S. and Brazil, for example, give preference to alternative fuel vehicles (Rajagopal & Zilberman, 2007).

2.4 Theoretical and Empirical Literature of Policy Impacts

Generally, government policies and support that are directly linked to levels of production and consumption are regarded as causing the most significant market distortions, while support for research and development are arguably the least distorting (FAO, 2008). Kojima *et al*. (2007) note some biofuel policies, such as mandates and fuel excise tax reductions that do not explicitly distinguish between domestically produced and imported biofuels, stimulate the consumption of biofuels and do not distort trade (except to the extent to which they may actually artificially stimulate it). However, other policy measures, in the form of import tariffs and/or producer subsidies (deficiency payments), provide clear protection and subsidisation of domestic production at the expense of foreign-produced biofuels.

By way of a social cost/benefit analysis, Gardner (2007) suggests that both subsidies and mandates for bioethanol are unlikely to generate net social gains. However, associated deadweight losses (e.g., misallocated scarce resources and reduced consumption) are expected to be relatively smaller in the short-run, when both demand and supply responses are small, than in the long-run, when both supply and demand are expected to be relatively more elastic and thus cause the deadweight losses to increase substantially. He notes further that for a given total subsidy cost, maize producers typically gain more from a deficiency payment subsidy than from a bioethanol subsidy. However, he concludes that although the primary beneficiaries of the bioethanol subsidy in the short-run are bioethanol producers, the long-run beneficiaries are actually the maize producers. Babcock (2008) also finds significant welfare losses from U.S. bioethanol policy, resulting in substantial transfers from taxpayers and non-ethanol maize users to maize growers, fuel blenders and bioethanol producers. He concludes that given the modest and relatively uncertain environmental benefits associated with bioethanol, it is unlikely that the associated public benefits outweigh the social welfare losses. In contrast, Wassell & Dittmer (2006) estimate that the external benefits associated with biodiesel production outweigh the required subsidies. Similarly, Hill *et al*. (2006) contend that biodiesel provides sufficient environmental advantages to merit subsidies.

Many authors have evaluated the possible effects of trade liberalisation, specifically the removal of bioethanol import tariffs in the U.S., on biofuel markets and social welfare (Martinez-Gonzalez *et al*., 2007; Rajagopal & Zilberman, 2007; Elobeid & Tokgoz, 2008; de Gorter & Just, 2008b; de Gorter *et al*., 2009). These authors note that such tariffs may actually contradict the objectives of improving the environment, reducing reliance on oil and diversifying energy sources, owing to the fact that maize-based bioethanol produced in the U.S. contributes significantly less to the reduction of greenhouse gases than sugarcane-based bioethanol produced in Brazil. Kruse *et al*. (2007), however, estimate that the removal of biofuel tax credits and bioethanol import tariffs in the U.S. would cause their domestic bioethanol production to contract by 30 percent and their biodiesel production by more than 50 percent.

Khanna *et al*. (2008) analyse U.S. bioethanol policy initiatives from a potential environmental impact standpoint, and have a key focus on their ability to address negative externalities associated with vehicle emissions and traffic congestion. Interestingly, these authors demonstrate that a bioethanol subsidy has the potential to increase carbon emissions, increase congestion, and lower social welfare by inadvertently stimulating consumers to increase the distances they drive.

Numerous authors have estimated that net farm income increases substantially with a continued expansion of biofuel production, mostly as a result of higher crop prices and sustained government support (Gardner, 2007; Walsh *et al*., 2007; Babcock, 2008; Gohin, 2008). Martinez-Gonzalez *et al*. (2007), however, stress that an analysis of welfare effects derived from an individual biofuel industry, such as the U.S. bioethanol market, is likely to underestimate the potential adverse impacts if it does not account for the deadweight losses that they may be generating in other markets. In this regard, many commentators have noted the potential adverse implications a continued biofuel expansion could have for livestock industries, by way of increased feed prices and other cost of production, such as fuel and fertiliser (Walsh *et al*., 2007; Anderson *et al*., 2008; Elobeid & Tokgoz, 2008; Gohin, 2008; Herdon, 2008; Tokgoz *et al*., 2008; Tiffany, 2009). Herdon (2008: 412) contends that “unlike row crop farmers, these agricultural producers do not have the luxury of record-high prices for their livestock products to offset these drastically higher feed costs”. Table 2.1 provides a summary of the expected impacts of selected policies on various environmental and economic indicators.

Table 2.1: Expected Impacts of Policies on Selected Economic and Environmental Indicators

Policy Tool	Oil Use Reduction	GHG Reduction	Farm Income	Biofuel Producers	Consumer Surplus (Food)	Consumer Surplus (Energy)	Government Budget
Energy & Fuel Policies							
Biofuel Tax Credit	+	<>	+	+	-	<>	-
Biofuel Mandate	+	<>	+	+	-	-	<>
Carbon Tax	+	+	<>	<>	<>	-	+
Efficiency Standard	+	+	<>	<>	<>	+	<>
Vehicle Subsidy	<>	<>	<>	<>	<>	<>	-
Agricultural & Trade Policies							
Price Support	+	<>	+	<>	<>	+	-
Acreage Control	<>	<>	+	-	-	-	-
Import Tariff	+	<>	+	+	-	-	+
Export Subsidy	<>	<>	+	+	-	-	-
Export Qouta	+	<>	-	+	+	+	<>
Where	+	Positive impact					
	<>	Uncertain impact					
	-	Negative impact					

Source: Adapted from Rajagopal and Zilberman (2007: 106).

Thus, Rajagopal and Zilberman (2007: 68) surmise the following:

- Most policies reduce consumption of crude oil at the national level, owing to either increased production of biofuel or a reduced demand for oil. Possible exceptions include acreage controls and export subsidies, which discourage domestic production and consumption, respectively. Export subsidies, however, may increase the global supply of biofuel, causing a global reduction in demand for oil.

- The majority of policies' abilities to reduce greenhouse gas emissions are largely uncertain, with the exception of policies that reduce the demand for oil (e.g., carbon taxes and efficiency standards). The uncertainty stems from the fact that emission reductions differ by crop, the intensity of input usage throughout the life cycle, and the nature of land-use changes etc. – all of which vary by location and with time.

- Policies that stimulate the production of biofuels typically have positive impacts on farm income.

- Biofuel producers are likely to gain or be unaffected by the majority of policies, with the exception of acreage controls which raise the costs of feedstock, and have negative impacts on producer surplus.

- Food and related markets are likely to be adversely affected due to rises in the prices of agricultural commodities associated with policies promoting the production of (first generation) biofuels.

- Impacts on consumer surplus are mixed. Taxes and mandates, which cause the overall price of energy to increase, reduce consumer surplus. The same is true for policies which restrict the production of feedstock. Efficiency standards, price supports for the production of biofuel crops, and export quotas raise consumer surplus by way of reducing the cost of energy service or by lowering the cost of biofuel feedstocks. The impact of agricultural and trade policies on consumer surplus for food are similar to the impacts of the policy on consumer surplus for energy.

- Taxes and tariffs generate revenue for government. In contrast, tax credits, price supports, acreage controls, and trade subsidies result in reduced government revenue, or increased government spending.

- Generally, most agricultural and trade policies benefit farmers, while energy policies address the problems that result from oil consumption.

It is, however, important to emphasise that the above analyses are applicable only to the single isolated policy, and, therefore, do not necessarily hold true when there are multiple policies in effect simultaneously. Analysing the marginal and interaction effects between multiple policies is a complex task; recent studies of this nature include de Gorter and Just (2008a, 2008b, 2009a, 2009b) and de Gorter *et al.* (2009).

2.5 South African Biofuel Policy Initiatives and Proposed Targets

The South African (SA) government has committed to comply with the framework of the Renewable Energy White Paper, which stipulates the production of renewable energy of 10 000 GWh (equivalent to 0.8Mtoe) [3] to be achieved by 2013 (DME, 2003), a portion of which has to come from the production of biofuels (Meyer *et al.*, 2008). This is approximately four percent of the projected electricity demand for 2013 (DME, 2003).

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[3] **GWh** (Gigawatt hour) is an energy unit in which electricity consumption is measured. (1 GWh = 3600 GJ (Gigajoule) (Joule is unit of energy)) (DME, 2003).
Mtoe (Million tons of oil equivalent) is a universal unit of comparison in which all energy can be measured. (1 Toe = 42 GJ = 0.042 TJ = 0.012 GWh) (DME, 2003).

Currently, however, renewable energy contributes relatively little to energy levels in South Africa (DME, 2003; Winkler, 2005).

A brief overview of the current SA biofuels industrial strategy is provided by Funke *et al*. (2009). Key aspects include the targeted two percent penetration level of biofuels in the national liquid fuel supply, equivalent to 400 million litres per annum, by 2013 (DME, 2007). Furthermore, the strategy recommends blending requirements of two and eight percent for biodiesel and bioethanol, respectively. These targets were proposed to be maintained until 2020. Additionally, the industrial strategy recommends that: (1) the current biodiesel fuel levy exemption be increased from 40 to 50 percent; (2) the small-scale producer's threshold be raised from 300 000 to 1.2 million litres per annum (the SA Revenue Service (SARS) permits a 100 percent exemption for these small producers); and (3) a 100 percent fuel levy exemption for bioethanol be introduced (DME, 2007).

The DME (2007) contend that these goals can be achieved without jeopardising food security. They estimate further that only 1.4 percent of arable land in South Africa would be required and approximately 25 000 jobs would be created in meeting these objectives. Although job creation is a key focus of the revised strategy, these estimates may well be optimistic. For example, Gohin (2008) contends that only 43 000 jobs will be created by meeting the EU's biofuel target of 5.75 percent of transport fuel by 2010. Interestingly, in the U.S. "small bioethanol and biodiesel producers" constitute plants producing less than 60 million gallons per annum. These producers are eligible for small producer excise tax credits, with a maximum credit of up to $1.5 million per annum (Eidman, 2007).

However, there still appears to be a lack of a clear and comprehensive policy framework for the development of a SA biofuels industry, as none of the above *proposed initiatives* have been implemented to date. There are also concerns among stakeholders that government policy is taking too long to formulate, compounding existing uncertainty in the industry. These concerns appear to be further aggravated by the fact that South Africa's commitment to the framework of the Renewable Energy White Paper is not binding. Therefore, if the targets for 2013 were not reached the government could simply "shift the goal posts" to a later target date. Thus, South Africa's biodiesel market is presently characterised by several small- and medium-scale producers (Amigun *et al*., 2008), which may be of direct consequence to existing biofuel policy given that the most support currently exists for producers operating below the small-scale producer threshold of 300 000 litres per annum. Importantly, Funke *et* *al*. (2009) contend that the incentives and commitments as proposed by the SA biofuels industrial strategy (DME, 2007) are inadequate to both establish and sustain a domestic biofuel industry. With specific reference to potential SA biodiesel production, Funke *et al*. (2009: 241) point out that "revised and more clearly defined strategies are required to stimulate the set up of a biodiesel industry that can eventually lead to the successful obtainment of the objectives as set out in the biofuel strategy". These authors, however, made no further attempt to quantify or propose possible policy measures.

There is perhaps too much current emphasis placed on development-oriented small-scale biofuel production in the SA context, with the expected outcomes from such ventures potentially being relatively unrealistic. Therefore, there is a clear need for *objective* research that quantifies and qualifies the level of SA government support required to promote local biofuel initiatives – both at the commercial and smallholder level. However, the need for government to play a proactive role in biofuel markets, at the very least through the provision of appropriate incentives, is clearly evident. Some additional biofuel policies that the SA government could consider for future biofuel promotion are summarised in Table 2.1. The following chapter presents a detailed review of factors which influence the economics of biodiesel production.

CHAPTER 3: FACTORS AFFECTING THE ECONOMICS OF BIODIESEL PRODUCTION

The foregoing chapters have explored prominent international debates and alternative policy measures and implications which have application to biofuels in general. Given that the objectives of this study are to determine the economic feasibility of on-farm biodiesel production on crop farms in KZN, this chapter focuses on technical and economic issues pertaining specifically to the biodiesel production process. Alternative feedstocks, scale of production, and studies of biodiesel production costs and feasibility are evaluated. Finally, some key aspects that play a significant role in determining the long-term success and viability of these ventures are presented.

3.1 General Overview

Meher *et al*. (2006) and Murugesan *et al*. (2009) suggest that diesel fuels have significant importance in the economies of developing countries. In this regard, Mulugetta (2008) notes that road transport is the dominant means of moving goods and services in Africa, accounting for approximately 85 percent of the total fossil fuel consumed in the transport sector - of which more than 55 percent comprise of diesel fuels. This emphasises the importance of diesel fuels to the African continent. In contrast, petrol is currently the dominant fuel-type in South Africa, with an estimated 11069 million litres of petrol and 9762 million litres of diesel being consumed in 2008 (SAPIA, 2008). However, the DME (2002) estimated that diesel comprised 54.7 percent of energy used in the SA agricultural sector. Comparable figures for petrol consumption were 3.3 percent, clearly illustrating the importance of diesel fuel to the agricultural sector in particular (DME, 2002). Figure 3.1 provides a summary of South Africa’s inland consumption of various petroleum products for the period 1988 to 2008.

Biodiesel is a diesel fuel, primarily alkyl (methyl or ethyl) esters (an organic compound with two oxygen atoms) of long-chain fatty acids derived from renewable feedstocks, such as oilseeds, waste vegetable oils, cooking oil, animal fats, trap grease, or other triglyceride-bearing biomass, such as microalgae, that can be used in blends or neat/pure form in compression-ignition engines (Haas *et al*., 2006; Kojima *et al*., 2007; Petrou & Pappis, 2009). Biodiesel is regarded as being a renewable diesel-fuel substitute, with the advantages of diminishing dependence on foreign petroleum, mitigating greenhouse gas emissions, and improving urban air pollution (Tareen *et al*., 2000). Similarly, Zhang *et al*. (2003b) and Siriwardhana *et al*. (2009) note that biodiesel is recommended for use as it is a renewable domestic resource with an environmentally friendly emission profile and is readily biodegradable, as well as being non-toxic in nature (Muniyappa *et al*., 1996; Meher *et al*., 2006; Marchetti *et al*., 2007; Murugesan *et al*., 2009). Since biodiesel can be produced from a variety of oils, the resulting fuels can display a wider variety of physical properties, such as viscosity and combustibility, than bioethanol (Worldwatch Institute, 2007; FAO, 2008). However, information on the production, quality specifications, performance, and emission properties of biodiesel have become increasingly available in the past three decades (Haas *et al*., 2006).

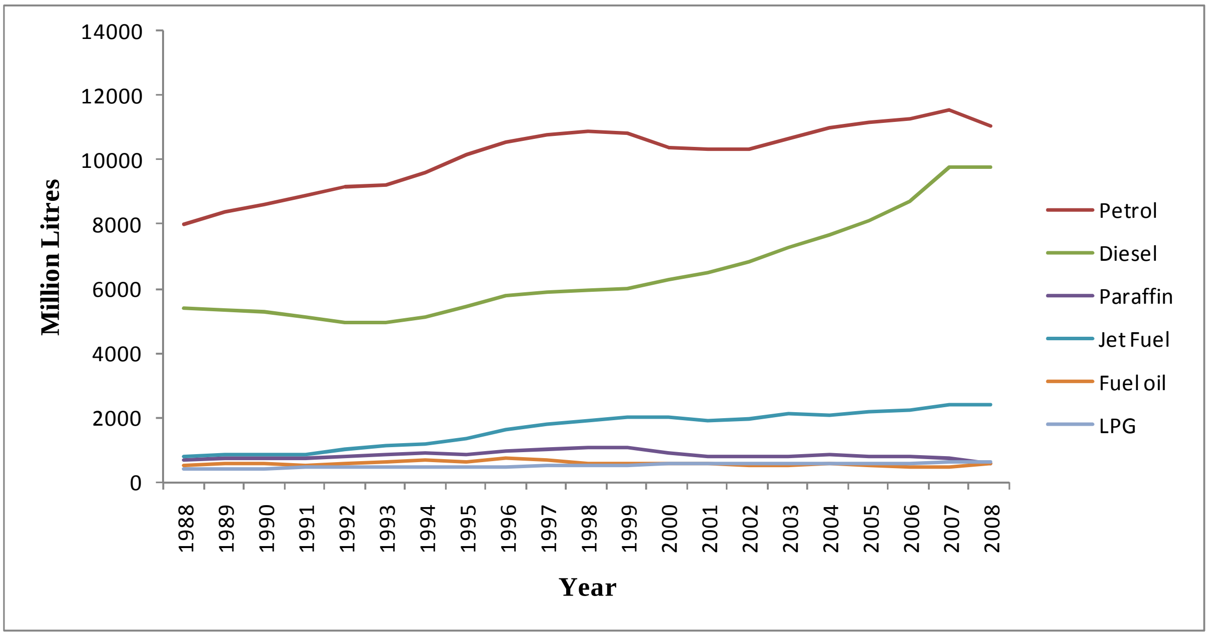

Figure 3.1: South African Inland Consumption of Petroleum Products, 1988-2008

Source: Adapted from SAPIA (2008: 59).

Hu *et al*. (2008) estimate that compared to conventional diesel, (soybean-based) biodiesel had 31, 44, 36, 29 and 67 percent lower source-to-wheel hydrocarbon, carbon monoxide, particulate matter, sulphur oxides (SO_x), and carbon dioxide emissions, respectively. However, it should be noted that nitrogen oxide (NO_x) emissions were comparatively 79 percent higher. Similar conclusions are reached by Basha *et al*. (2009) for a variety of biodiesel feedstocks. Furthermore, biodiesel can generally substitute for petroleum diesel fuel in diesel engines with minor modifications and a slight reduction in power and fuel efficiency (Raneses *et al*., 1999). The FAO (2008) notes that biodiesel's energy content is typically 88 to 95 percent of that of diesel; however, biodiesel improves the lubricity of diesel and raises the cetane value, resulting in the fuel economy of both generally being comparable. For these reasons, Tareen *et al*. (2000) and Sharma and Singh (2008) suggest that biodiesel has the potential of (partially) displacing petroleum diesel as an engine fuel in the long-run, as these benefits hold true not only for neat biodiesel but for blends too. Subsequently, campaigns have been planned in numerous countries to introduce and encourage the use of biodiesel (Carraretto *et al*., 2004), resulting in increased production of biodiesel in recent years (Haas *et al*., 2006; Martinot, 2005, 2007, 2009). This trend is expected to continue in the future (Haas *et al*., 2006). Russi (2008: 1171), however, contends that "the amount of biodiesel to be produced is a genuine political decision and does not really depend on market trends".

Under current production patterns the leading five biodiesel producing nations by volume, in descending order, are Germany, U.S., France, Argentina and Brazil (Martinot, 2009). Johnston and Holloway (2007), however, estimate that there is significant potential for the expansion of biodiesel production worldwide. Table 3.1 lists the top ten nations ranked in terms of overall biodiesel production volume potential. The average feedstock dependence among these countries is 28, 22, 20 and 11 percent for soybean oil, palm oil, animal fats and coconut oil, respectively, whilst the remainder is distributed among rapeseed, sunflower and olive oils (Johnston & Holloway, 2007). The development of the biodiesel industry on the African continent, however, is still in its infancy (Amigun *et al*., 2008b).

Table 3.1: Leading Countries in Terms of Absolute Biodiesel Production Potential

Rank	**Country**	**Volume Potential (million litres)**	**Production Cost ($/litre)**	**Rank**	**Country**	**Volume Potential (million litres)**	**Production Cost ($/litre)**
1	Malaysia	14540	0.53	6	Netherlands	2496	0.75
2	Indonesia	7595	0.49	7	Germany	2024	0.79
3	Argentina	5255	0.62	8	Philippines	1234	0.53
4	USA	3212	0.70	9	Belgium	1213	0.78
5	Brazil	2567	0.62	10	Spain	1073	1.71

Source: Adapted from Johnston and Holloway (2007: 7970).

A common criticism of biodiesel, however, is that its properties at low temperatures are inferior to those of conventional diesel fuel (Carraretto *et al*., 2004; Demirbas, 2007; Kojima *et al*., 2007; Worldwatch Institute, 2007; Sharma & Singh, 2008). This is because biodiesel has a greater tendency to form wax at low temperatures and subsequently clogs fuel filters, thus posing technological challenges in relatively cold climates and in winter applications in temperate climate countries (Kojima *et al*., 2007). Furthermore, Carraretto *et al*. (2004) caution that when using biodiesel, tanks should be carefully cleaned before storage, due to the detergent properties of some cleaning chemicals; and since the fuel is not compatible with some plastic materials used in pipes and gaskets, resistant materials should be used (e.g., Viton or Teflon). Other problems associated with using biodiesel directly in diesel engines are discussed by Murugesan *et al*. (2009).

Nevertheless, “biodiesel technology is making the transition from a research endeavour to a worldwide commercial enterprise” (Haas *et al*., 2006: 672). Amigun *et al*. (2008a: 698) suggest that the economics of biofuel production and consumption will depend on a number of interrelated factors that are specific to the local situation, including (i) the cost of biomass feedstock (which varies between countries according to land availability, agricultural productivity, labour costs, etc.); (ii) biofuel production costs (which varies among countries and depends on the plant location, size and technology); (iii) the cost of domestic fossil fuel (which depends on fluctuating oil prices, exchange rate, and domestic refining characteristics); and (iv) the strategic benefit and importance of substituting imported oil with domestic resources. Clearly, the economics of biodiesel production and use will likely differ by country and individual project situation.

3.2 Biodiesel Production Process

An important economic consideration in manufacturing biodiesel is the choice of production process, as significant capital and operating cost differences exist (Amigun *et al*., 2008b). The technologies available for converting vegetable oils and animal fats into biodiesel have been researched extensively (Zhang *et al*., 2003a, 2003b; Haas *et al*., 2006; Marchetti *et al*., 2007; Basha *et al*., 2009). Van Gerpen and Knothe (2005: 26) and You *et al*. (2008: 182) contend that biodiesel may be obtained by four primary means: (i) direct use and blending of oils; (ii) microemulsions of oil; (iii) thermal cracking (pyrolysis of vegetable oil); and (iv) transesterfication. Presently, however, the most frequently used means to produce biodiesel is to transesterify triacylglyerols in vegetable oils or animal fats with an alcohol (i.e., transesterfication), in the presence of either an alkali or acid catalyst (Zhang *et al*., 2003a, 2003b; Rajagopal & Zilberman, 2007; You *et al*., 2008). Catalysts are typically used to improve transesterfication reaction rates and yields (You *et al*., 2008).

Haas *et al*., (2006) suggest that the choice of chemical technology to utilize in a production plant depends on the available feedstock and its quality. Furthermore, these authors note that the choice of conversion technology and the scale of production will directly influence both capital and operating costs. There appears to be consensus, however, that the alkali-catalysed transesterfication is the most commonly utilised process, particularly for commercial biodiesel production (Zhang *et al*., 2003b; Amigun *et al*., 2008a, 2008b; You *et al*., 2008). This is due to its thorough and comparatively faster reaction rate than acid-catalysed transesterfication (Zhang *et al*., 2003b; Demirbas, 2007; Basha *et al*., 2009; Murugesan *et al*., 2009). Moreover, the reaction occurs at a relatively lower temperature and pressure, resulting in lower capital and operating costs (Demirbas, 2007; Amigun *et al*., 2008a, 2008b). Similarly, Zhang *et al*. (2003b) suggest that capital costs are significantly lower for alkali-catalysed processes. Therefore, Amigun *et al*. (2008a, 2008b) conclude that the alkali-catalysed transesterfication process is typically the most economical means of producing biodiesel. You *et al*. (2008) note that a limitation to the alkali-catalysed process is its sensitivity to the purity of reactants, and is particularly sensitive to both water and free fatty acids (FFAs). A comprehensive review of other technical aspects of biodiesel production through the transesterfication process is provided by Meher *et al*. (2006).

The sale and/or productive use of by-products contribute to the viability and competitiveness of biodiesel plants (Coyle, 2007; Amigun *et al*., 2008b). Glycerine is produced as a by-product of transesterfication (Zhang *et al*., 2003a; Marchetti *et al*., 2007; Rajagopal & Zilberman, 2007; You *et al*., 2008). The production process also typically yields additional by-products such as crushed bean cake/meal, which can be used as a protein-rich input in animal feeds (Kenkel & Holcomb, 2006; Amigun *et al*., 2008b; FAO, 2008). Furthermore, Amigun *et al*. (2008b) note that separated FFAs can sometimes be sold for further processing to the oleo-chemical industry, and in some cases potassium sulphate fertilizer is another by-product from biodiesel production.

Amigun *et al*. (2008b) note that glycerine can constitute as much as 10 percent of the product created in the processing of biodiesel. Raneses *et al*. (1999) suggest that glycerine is a valuable by-product which can be used in pharmaceuticals, cosmetics, toothpaste, and numerous other commercial products, such as food-processing and feed applications (Coyle, 2007), and the development of films and casing materials (Kenkel & Holcomb, 2006). Numerous authors note that the credit for the sale of the glycerine by-product has a significant impact on the net value of the total manufacturing cost of biodiesel (Nelson *et al*., 1994; Bender, 1999; Zhang *et al*., 2003b; Haas *et al*., 2006; Amigun *et al*., 2008b). For example, Zhang *et al*. (2003b) and Haas *et al*. (2006) estimate that this credit could result in a reduction of production costs of approximately 10 and six percent, respectively. Amigun *et al*. (2008b) suggest that a typical biodiesel plant yields crude glycerine of approximately 80 percent purity. Haas *et al*. (2006), however, note that substantial commercial value of this by-product is invariably only realised if the glycerine is fully purified, which is a relatively expensive process. These authors subsequently suggest that small to medium sized operations often find it most cost effective to only partially purify the glycerine (by removing methanol, fatty acids and most of the water) and then selling the product to industrial glycerine refiners. Bender (1999) and Amigun *et al*. (2008b) contend that glycerine markets are volatile, and suggest that extensive biodiesel production could potentially flood the glycerine market and drive glycerine prices down. A similar view is held by Muniyappa *et al*. (1996). Amigun *et al*. (2008b) suggest further that a substantial drop in the glycerine price would affect the profitability of biodiesel production in the sense that only large-scale producers may find it profitable to refine glycerine. Eidman (2007) concludes that glycerine currently has a very limited market.

Kenkel and Holcomb (2006) note that depending on the feedstock variety used, the feed by-product from oilseed-based biodiesel production represents between 60 and 80 percent of the feedstock weight. These authors suggest further that although protein content varies across feedstock varieties, oilseed meals are regarded as protein-rich feed sources which are suitable for both ruminant and non-ruminant livestock. For example, Bender (1999) notes that sunflower and rapeseed meal have lower nutritional quality than soybean meal and, therefore, command less value on the agricultural market than soybean meal. He suggests further that the relatively high market price of soybean meal coupled with the fact that a large amount of meal resulting from the relatively low oil content of soybeans (see Table 3.2) may actually result in soybean-based systems having the lowest total production cost – despite soybeans typically being the most expensive raw feedstock. A similar conclusion is reached by Meyer *et al*. (2008). Kenkel and Holcomb (2006) and Eidman (2007) suggest that the marketing of feed by-products in particular may become a limiting factor for the success of U.S. biodiesel facilities in the future, as they may contribute to an oversupply in the feed protein market. Whether a similar situation exists in developing countries, however, is highly debatable. Figure 3.2 illustrates a typical flow chart of a biodiesel production process.

Nguyen and Prince (1996) emphasize the importance of determining the optimum (least-cost) plant capacity for biofuel processing facilities. According to Amigun *et al.* (2008a), a significant technological issue in the production of biodiesel is whether a batch or continuous flow plant should be constructed. Eidman (2007) notes that the majority of biodiesel plants in the U.S. currently use continuous flow processes. Continuous flow plants appear to be preferred for large-scale operations (Amigun *et al.*, 2008a), and have the ability to produce continuously within set parameters. Due to the generally larger scale of production required, continuous flow processes typically have comparatively higher capital costs than batch processes (Eidman, 2007; Amigun *et al.*, 2008a). However, higher capital outlays may be mitigated by several important operational advantages, such as lower processing costs and generally more consistent output than batch processes (Eidman, 2007). Lower processing costs may arise from the ability to re-use catalysts and other chemicals which is often infeasible in batch processes (Bender, 1999; Amigun *et al.*, 2008a).

Batch processes allow a quantity of biodiesel to be processed in separate consignments. Amigun *et al.* (2008a) contend that the comparatively lower initial capital requirements and the ability to regulate production within demand results in batch processes typically being better suited to small-scale production operations, and thus to the African continent. These authors suggest further that since government energy policies in Africa are often regarded as being both uncertain and unpredictable, investors may combat risk by favouring ventures with relatively smaller capital outlays.

3.3 Biodiesel Feedstocks

Eidman (2007) and Kojima *et al*. (2007) note that there is currently limited biodiesel production from animal fats and recycled waste oils, and emphasise that there is little scope for expanding biodiesel supply from these sources, as producers struggle to collect and process sufficient quantities to provide a constant supply for a large-scale production plant. Surprisingly, the opposite view is held by Gui *et al*. (2008: 1652), who contend that waste edible oils should be the primary feedstock for biodiesel production due to their "abundant availability". Nevertheless, Nelson *et al*. (1994) point out that the above materials are often less expensive than most oils produced from oilseed crops such as soybeans, rapeseed and sunflower. This may be due to the fact that animal fats and waste greases typically have lower capital and operating costs than the oilseeds since the press and oil extruder are not required (Bender, 1999).

There is broad consensus that the majority of biodiesel is currently produced from vegetable oils (Eidman, 2007; Kojima *et al*., 2007; Worldwatch Institute, 2007; Banse *et al*., 2008; Gui *et al*., 2008; Morrone *et al*., 2009). However, the choice of feedstock is often based on variables such as local availability, governmental support and general performance as a fuel (Haas *et al*., 2006). Similarly, Sharma and Singh (2008) contend that the choice of raw materials depends largely on its availability and, importantly, cost. Nevertheless, a comprehensive review of the fuel properties and performance of biodiesel produced from animal fats is provided by Wyatt *et al*. (2005).

Evidently, a wide variety of biomass feedstocks are used for biodiesel production (Petrou & Pappis, 2009). Demirbas (2007) and Basha *et al*. (2009) contend that more than 350 oil-bearing crops have been identified worldwide. However, not all of these are considered suitable for biodiesel production. The FAO (2008) suggest that oil used for biodiesel production can be extracted from most oilseed crops. Soybeans are currently the dominant oilseed crop cultivated worldwide (Worldwatch Institute, 2007). Therefore, it is not surprising that, globally, the prominent biodiesel feedstocks include soybeans in Brazil, Argentina and the U.S. and rapeseed in Europe. In tropical and subtropical countries biodiesel is increasingly produced from palm, coconut and *Jatropha* oils. Table 3.2 provides a brief summary of agronomic data for selected oilseed crops.

Table 3.2: Agronomic Data for Selected Oilseed Crops

Oilseed Crops	Oil Content (% of Seed Weight)	Minimum Water Requirement (mm/annum)	Maximum Water Requirement (mm/annum)	Trees/ha	Average Crop Yield (kg/ha)	Avergae Oil Yield (kg/ha)	Oil Yield/Unit Water (kg/mm)	Time to Full Maturity	Productive Life (Years)
Coconut	70	600	1200	100	na	4500	5.00	5-10 Years	50
Oil Palm	80	1800	2500	150	na	5000	2.33	10-12 Years	25
Groundnut	50	400	500	na	1015	508	1.13	100-120 Days	na
Rapeseed	40	350	450	na	830	332	0.83	120-150 Days	na
Castor	45	500	650	na	1100	495	0.86	150-280 Days	na
Sunflower	40	600	750	na	540	216	0.32	100-120 Days	na
Soybean	18	450	700	na	1105	199	0.35	100-150 Days	na
Jatropha*	30	150	300	2000	2000	600	2.67	3-4 Years	20
Pongamia*	30	150	300	1000	5000	1500	6.67	6-8 Years	25

*** Crop not grown commercially, calculations based on estimates**

Source: Adapted from Rajagopal and Zilberman (2007: 102).

Eidman (2007) contends that the supply of biodiesel feedstocks is a significant factor limiting the development of the U.S. biodiesel industry. However, the Biofuels Industrial Strategy of the Republic of South Africa recommends that *Jatropha* be excluded from consideration for the production of biodiesel, as “future research is still needed to test the usability” of this feedstock in South Africa (DME, 2007: 3). Nevertheless, *Jatropha* plants are expected to have significant oil yield potential, particularly in arid regions (see Table 3.2). Recent international studies on the potential of *Jatropha* as a biodiesel feedstock include Tiwari *et al*. (2007), de Oliveira *et al*. (2009) and Gunaseelan (2009). Nevertheless, De Oliveira *et al*. (2009) conclude that further agronomic studies are still necessary to enhance the seed production and crude oil properties of *Jatropha*.

3.4 Studies of Biodiesel Production Costs

Johnston and Holloway (2007) and Amigun *et al*. (2008a) note that biodiesel production costs typically vary by geographic region and choice of feedstock (see Table 3.1). In this regard, Mulugetta (2008) suggests that the factors of production for manufacturing biodiesel in Sub-Saharan Africa and in other developing countries are likely to be different from those in industrialised countries, due to differences in technological and managerial capability and associated labour costs. Amigun *et al*. (2008b) contend that the labour component of production costs depends on the production scale of the plant (production capacity), the level of sophistication (degree of automation), the type of process (batch or continuous), and the feedstock variety processed. Mulugetta (2008) notes further that because there is currently a general lack of empirical experience with respect to biodiesel production in Africa, local studies often make use of production data from Europe and North America.

There appears to be consensus that raw materials are the most significant cost element of biodiesel production (Nelson *et al.*, 1994; Withers & Noordam, 1996; Van Dyne & Blase, 1998; Bender, 1999; Fortenberry, 2005; Nelson & Schrock, 2006; Coyle, 2007; Demirbas, 2007; Eidman, 2007; Amigun *et al.*, 2008a, 2008b; Mulugetta, 2008; Petrou & Pappis, 2009). The cost share of feedstock typically varies by study and feedstock variety. For example, Tareen *et al*. (2000) note that soybean prices account for approximately 75 percent of soybean-based biodiesel production costs. However, Haas *et al*. (2006) estimate that this may be as high as 88 percent using crude, degummed soybean oil as feedstock. By comparison, Weber (1993) and Withers and Noordam (1996) estimated that feedstock costs comprised 64 and 70 percent of total costs, respectively, using rapeseed as feedstock. Mulugetta (2008) estimates oil palm accounts for more than 85 percent of production costs in Ghana; and Nelson and Schrock (2006) estimate a cost share of approximately 81 percent when using beef tallow as feedstock. Coyle (2007) suggests that with recent trends of rising agricultural commodity prices, the cost share of feedstock may continue to increase in the future. Therefore, Amigun *et al*. (2008a) conclude that feedstock costs are typically the single most important factor that influences the economic feasibility of biodiesel production.

Amigun *et al*. (2008a, 2008b) suggest that despite capital expenditure usually being the primary barrier that must be overcome in establishing a biodiesel production plant, the long-term success of such ventures are frequently more dependent on the daily operating efficiency than on the initial capital expenditure. For example, high operating expenses, low and/or inconsistent product quality and yields may result in the failure of the biodiesel production facility. This is because capital cost is typically a relatively small share of total cost (approximately five percent in the industrial-scale production of biodiesel) (Amigun *et al*., 2008b). Similarly, Weber (1993) estimated that capital costs only constitute a small proportion of total operating expenses (less than 10 percent). Haas *et al*. (2006) contend that significant components (nearly one-third) of equipment costs are for feedstock and product storage tanks. These authors, therefore, suggest that substantial savings could arise from reducing storage capacity; for example, by negotiating timely removal of products, or accepting reduced inventory holding capacities.

Amigun *et al*. (2008b) suggest that capital costs are influenced by the plant's capacity and location. In this regard, Kenkel and Holcomb (2006: 371) suggest that significant factors influencing the economics of locating and operating biofuel plants include: (i) feedstock availability; (ii) access to market centres for biofuels; (iii) access to markets for by-products; (iv) utility costs and availability; and (v) state/local incentives. Similarly, Lambert *et al*. (2008) suggest that the location of bioethanol plants in the U.S. is determined by infrastructure, product and input markets; fiscal attributes of local communities; and state and federal incentives. These authors suggest further that the availability of feedstock dominates the site selection decision, while access to by-product markets and transport infrastructure are also important factors. A similar view is held by Tiffany and Eidman (2003). It is not surprising, therefore, that Kenkel and Holcomb (2006) observe that the majority of existing bioethanol and biodiesel plants in the U.S. are concentrated in areas of high crop production, such as Illinois, Iowa, Nebraska, Minnesota, and South Dakota. Accordingly, Amigun *et al*. (2008b) note that the economics of biodiesel production will be significantly influenced by localised variables, and suggest that locations that offer relatively low utility rates (e.g., electricity), existing infrastructure, and high feedstock availability would be preferable production sites. Coyle (2007) contends that energy is a noteworthy production cost component, which may account for as much as 20 percent in some countries. However, Kenkel and Holcomb (2006) note that biodiesel plants are typically relatively low-utility operations compared to bioethanol plants.

Prominent empirical evaluations of biodiesel production costs include Bender (1999), who reviewed 12 economic studies of biodiesel production involving several varieties of feedstocks and operational scales. Estimated total production costs ranged from U.S. \$0.30/litre for biodiesel produced from soybeans to U.S. \$0.69/litre using rapeseed as feedstock. Bender (1999) concludes that the economics of biodiesel production can be regarded as being relatively volatile, primarily due to the significant effects of feedstock cost and meal credits. He notes further that factors such as capital costs, electricity costs and glycerine credits can also have a prominent influence on the production costs for biodiesel.

Zhang *et al*. (2003a, 2003b) designed and simulated four different continuous flow processes for biodiesel production. These authors contend that despite the alkali-catalysed process using virgin vegetable oil as feedstock having the lowest fixed capital cost, the acid-catalysed process using waste cooking oil was a more economically viable alternative. You *et al*. (2008) evaluate the economic costs of three biodiesel plants with capacities of 8000, 30 000 and 100 000 tons of biodiesel per annum. These plants employed continuous flow processes using an alkali catalyst, and the raw material of soybean oil. Of the economic variables that they analysed, these authors suggest that plant capacity, prices of feedstock and diesel, and yields of both biodiesel and glycerine were the most significant factors affecting the economic viability of producing biodiesel. A summary of the findings of these and other selected economic evaluations of biodiesel production costs is provided in Appendix B.

Meyer *et al*. (2008: 333) estimated the profitability of producing biodiesel using either soybean or sunflower as feedstock for an “average sized plant” in South Africa during 2006. Their results are presented in Table 3.3. Unfortunately, the authors do not provide an exact specification of the plant’s capacity. Moreover, only the sale of oil cake was accounted for, while credits from other by-products, such as glycerine, which could further enhance the estimated gross margins, were ignored. However, Meyer *et al*. (2008) conclude that neither sunflower nor soybean feedstocks would yield a positive plant profit by producing biodiesel under 2006 market conditions in South Africa.

Table 3.3: South African Biodiesel Plant Profit Calculations, 2006 Prices

Feedstock	Cost (R/ton)	Income from byproduct (R/ton)	Income from biodiesel sales (c/litre)	Total costs of production (c/litre)	Profit (c/litre)
Soybeans	1959	2076	336.45	366.30	-29.87
Sunflower	2338	1505	336.45	598.55	-262.27

Source: Adapted from Meyer *et al.* (2008: 333).

Since feedstock costs comprise a significant proportion of total biodiesel production costs, numerous authors conclude that the future promotion of biodiesel production should primarily target the reduction of feedstock costs through the development of new technologies which increase yields of available feedstocks, and/or allow the use of lower cost alternatives (Withers & Noordam, 1996; Zhang *et al*., 2003b; Haas *et al*., 2006; Coyle, 2007; Amigun *et al*., 2008b; You *et al*., 2008). Amigun *et al*. (2008b) also emphasize the need to explore possible new applications for the glycerine by-product.

3.5 Scale of Biodiesel Production

Amigun *et al.* (2008a) suggest that existing bioethanol plants in Africa are currently geographically concentrated in the Southern African Development Community (SADC) countries, as well as in Ethiopia and Kenya. However, biodiesel technology can still be regarded as an emerging technology on the African continent (Amigun *et al.*, 2008a, 2008b), with the possible exception of South Africa and Zimbabwe (Amigun *et al.*, 2008b). Interestingly, these authors observe that while the African continent's first commercial biodiesel plant was recently established in Zimbabwe, small-scale biofuel plants currently dominate biofuel production in Africa.

Perloff (2007: 204) notes that a cost function exhibits economies of scale if the average cost of production decreases as output expands. Peters and Thielmann (2008) suggest that the most prominent biofuel promotion policy instruments – mandatory blending quotas and tax exemptions – are designed to primarily generate economies of scale via stimulating demand. They, therefore, contend that the success of these measures depends on whether the average production costs can be sufficiently reduced to make biofuels commercially viable alternatives. However, Bender (1999) contends that biodiesel production costs do not reflect economies of scale, since scale-dependent expenses such as labour only constitute a small proportion of the operating costs. Amigun *et al.* (2008b) find some evidence of economies of scale for labour in biodiesel plants. However, they conclude that since the single most important factor influencing the economic viability of biodiesel are feedstock costs there are no significant economies of scale involved in the biodiesel production process. Similarly, Amigun *et al.* (2008a) contend that biodiesel production facilities are relatively insensitive to economies of scale. In contrast, Eidman (2007) finds evidence of economies of scale for both bioethanol and biodiesel plants in the U.S. However, he contends that the gains in production efficiency that may accrue to larger processing facilities will not be sufficient to replace the excise tax credit that has stimulated rapid growth in these industries in the U.S. in recent years.

Mulugetta (2008) suggests that discussions surrounding biofuels in Africa are partly an attempt to gain more control and independence over energy supplies by exploring and evaluating the quantity of biofuel that can realistically be produced from domestic resources; but also has elements of energy security, poverty reduction and fiscal stability. In this regard, Peters and Thielmann (2008) and Russi (2008) expect that biofuel promotion will increase the value-added component in the agricultural sector, and in so doing contribute to both rural employment and development. Amigun *et al*. (2008b) note that African biodiesel production programmes could make a significant contribution to poverty alleviation on the continent through job creation and by stimulating economic activity in rural areas. Similarly, Van Dyne *et al*. (1996) suggest that biodiesel production in rural communities has the potential to increase economic activity through job creation and an increased tax base.

However, although the overall employment effects from the operational side of a biodiesel plant will likely be positive, these new jobs may be partially offset by job losses in other industries (Van Dyne *et al*., 1996; Peters & Thielmann, 2008), such as the fuel, high-protein meal, and grain handling industries (Van Dyne *et al*., 1996). These authors suggest further that temporary jobs may be created during the establishment phases of biodiesel plants. Nevertheless, Van Dyne *et al*. (1996) conclude that small-scale, community-based biodiesel production and local ownership hold significant potential to provide benefits to both the agricultural sector and rural communities. Similarly, the Worldwatch Institute (2007) suggest that larger-scale biofuel production may result in greater industry concentration, be of less benefit to local communities, and will likely require more complex infrastructure, such as the use of pipelines and large processing facilities. They contend that this could lead to political, economic, social and environmental effects more similar to those of fossil fuels.

It has been suggested that small-scale, community-based biodiesel production opportunities are most suitable for diversified cropping and livestock enterprises, which produce oilseeds and have a need for a dietary protein source, such as oilseed meal, for livestock rations (Weber, 1993; Van Dyne *et al*., 1996). Furthermore, the small-scale, community-based concept appears to have the greatest potential for success where a large difference between the relative prices that farmers obtain for their oilseed and the price paid for high-protein meal exists (Weber, 1993; Van Dyne *et al*., 1996; Van Dyne & Blase, 1998; Bender, 1999). Van Dyne and Blase (1998) suggest that the larger the price difference, the greater the potential for profitability and financial success of such ventures. These authors contend further that potential benefits arise primarily because the farmer/feeder internalises the transaction costs relative to the conventional marketing system by using both the high-protein meal and biodiesel on their farms. This situation, however, will likely be location specific and may not be apparent in all areas (Van Dyne *et al*., 1996; Van Dyne & Blase, 1998). Interestingly, however, Weber (1993) indicates that soybeans are often the most viable feedstock to use in a community-based operation, primarily due to the high value of the feed by-product.

Kenkel and Holcomb (2006, 2009) note that agricultural producers have been actively involved in the growth and development of both bioethanol and biodiesel industries in the U.S., with a significant proportion of operational plants being farmer-owned, reflecting their producers continued interest in value-added activities. These authors, however, suggest that the proportion of farmer-owned plants in the U.S. appears to be decreasing as the rapidly increasing size and scale of both bioethanol and biodiesel plants makes it progressively more difficult for individual producers or farmer groups to finance these ventures. Furthermore, this trend has been compounded by the willingness of outside investors to participate in the biofuel industries in the U.S. In fact, Hettinga *et al*. (2009) estimate that the average size of dry grind bioethanol plants in the U.S. has increased by approximately 235 percent since 1990. A similar view is held by Gordon (2008), who also suggests that in the future the dependence of second generation biofuels on patented technology and seedstocks that are protected by trade regulations may serve to compound the prominent influence of agribusiness and biotech multinationals in bioenergy markets. She suggests further that if small-scale producers continue to lack the capital, infrastructure or economies of scale to access global biofuel markets, they may be able to participate in biofuel production only as suppliers of raw materials.

Small-scale producers in Ohio, interviewed by Morrone *et al*. (2009), suggested that feedstock availability and price competitiveness were the most significant challenges to their operations; whilst technical problems, public scepticism, regulatory concerns, and access to financial capital were also identified. It should, however, be noted that this sample only comprised of five small-scale producers. Han *et al*. (2008) report very similar challenges experienced by small-scale bioenergy ventures in rural China.

In addition to economies of scale, the unit costs of many goods and services tend to decrease with increasing experience in the industry (Goldemberg *et al*., 2004). This effect is often referred to in the economic literature as learning by doing, progress curves, experience curves, or learning curves. Perloff (2007: 210) suggests that this effect may be a function of time and/or cumulative output in an industry. Hettinga *et al*. (2009) suggest that experience curves link developments in production costs (or prices) with cumulative production, thus representing accumulated experience of production. This concept has been applied to the production costs of numerous renewable energy technologies, a general overview of which is provided by McDonald and Schrattenholzer (2001).

Hettinga *et al*. (2009) and van den Wall Bake *et al*. (2009) found evidence of experience curve effects in the maize-based and sugarcane-based bioethanol industries in the U.S. and Brazil, respectively. These authors estimate that in both countries production costs in these industries have declined by approximately 60 percent since 1975. Goldemberg *et al*. (2004) also found evidence of experience curve effects in the Brazilian bioethanol industry. Hettinga *et al*. (2009) suggest that in the case of U.S. maize-based bioethanol the decline in production costs can be attributed to higher maize and bioethanol yields associated with continued technological advancements, increased average bioethanol plant size, and lower energy use. Van den Wall Bake *et al*. (2009) contend that it is also likely that the net energy balance of the bioethanol has improved over time, due to higher yields per hectare, more efficient transport systems, and superior conversion technologies.

A prominent application of experience curve analyses is their extrapolation to investigate potential future production cost reductions as a function of projected future production levels (Hettinga *et al*., 2009; van den Wall Bake *et al*., 2009). In this regard, both these sets of authors estimate significant future bioethanol production cost reductions in the U.S. and Brazil. Hettinga *et al*. (2009), therefore, conclude that despite being regarded as first generation biofuel technologies, considerable cost reductions may continue to occur in the future. Importantly, however, van den Wall Bake *et al*. (2009) conclude that the Brazilian bioethanol industry in particular demonstrates how both early and continued governmental support can lead to significant reductions in production costs, now allowing Brazilian sugarcane-based bioethanol to compete directly with conventional fossil fuels without subsidies. Essentially, their infant industry has grown up. These authors note that similar studies are currently being conducted in Germany’s biodiesel industry. However, given the presence of experience curves in bioethanol industries, it would not be surprising if comparable conclusions were established for biodiesel production.

Given the relative insensitivity of biodiesel to economies of scale and the current general lack of a clear and comprehensive government biofuel policy on the African continent, Amigun *et al*. (2008a, 2008b) suggest that a possible implication could be that it may be preferable to construct a relatively large number of small, decentralised biodiesel plants rather than large-scale centralised biodiesel plants in Africa, as a means of combating risk whilst gaining valuable experience in the production of biodiesel. Similar recommendations are made by Collins-Chase (2005) and Nolte (2007). Nevertheless, the Worldwatch Institute (2007: 133) postulates that “despite well-meaning efforts to encourage small-scale biofuel production in many countries, larger-scale owners and corporations will probably still dominate the future biofuel industry”.

3.6 Biodiesel Feasibility Studies

A common argument against the use of various biofuels are their high costs of production, although this is no longer the case for sugarcane-based bioethanol produced in Brazil (van den Wall Bake *et al.*, 2009). Presently, however, there appears to be consensus that a significant barrier to the commercialisation of biodiesel is its comparatively higher production cost than conventional diesel fuel (Muniyappa *et al.*, 1996; Zhang *et al.*, 2003a, 2003b; You *et al.*, 2008). Tareen *et al.* (2000) note that neo-classical economic principles propose that if two inputs (e.g., biodiesel and conventional diesel) are perfect substitutes in production, the first-order condition of least-cost production is simplified to a direct comparison of input costs. Numerous studies have established that biodiesel is more costly to produce than conventional diesel and subsequently conclude that biodiesel production is not economically feasible (Griffin *et al.*, 1985; Nelson *et al.*, 1994; Withers & Noordam, 1996; Ahouissoussi & Wetzstein, 1997; Bender, 1999; Fortenberry, 2005; Haas *et al.*, 2006; Wassell & Ditmer, 2006; Whittington, 2006; Demirbas, 2007; Eidman, 2007; Nolte, 2007; Sawyer, 2007; Amigun *et al.*, 2008b; Siriwardhana *et al.*, 2009).

For example, Eidman (2007) estimated that average biodiesel prices in the U.S. since January 2005 were approximately $1.25 per gallon higher than the average U.S. wholesale price of diesel fuel. He notes further that purchasers of biodiesel had received approximately $1.00 of this difference through the refund of the volumetric excise tax credit, inferring that biodiesel had been selling at a premium of approximately $0.25 per gallon. Tareen *et al.* (2000) suggest that without considering the potential positive externalities associated with biodiesel production, economic agents would not substitute biodiesel for conventional biodiesel until there is a reversal in the relative prices of the fuels that they are facing. These authors suggest further that neo-classical theory proposes that economic agents that do not internalise the positive externalities of biodiesel production would require a subsidy equal to the amount of the price differentials. It is, therefore, not surprising that Eidman (2007) concludes that continued growth of the biodiesel industry in the U.S. is highly dependent on the continuation of the excise tax credit, or alternatively another form of subsidy to replace it. Similarly, several studies reach the conclusion that tax incentives and/or subsidies are necessary for biodiesel to become competitive with conventional diesel (Ahouissoussi & Wetzstein, 1997; Bender, 1999; Fortenberry, 2005; Wassell & Ditmer, 2006; Demirbas, 2007; Martinez-Gonzalez *et al*., 2007; Nolte, 2007; Amigun *et al*., 2008b; Peters & Thielmann, 2008). Amigun *et al*. (2008b), however, contend that while a subsidy would be useful in the establishment phase of the plant, it would not fully address the primary concerns of investors which are related to fluctuations in the dominant feedstock cost component.

The Worldwatch Institute (2007) suggest that outside of Europe, disparities between the prices of conventional diesel and biodiesel are typically larger than for petroleum and bioethanol. They attribute this primarily to oilseed crops grown in temperate regions being relatively more expensive to produce than sugar or starch crops, since they are less productive per unit of land. Nelson *et al*. (1994), however, note that although biodiesel typically costs more than conventional diesel, the total costs of biodiesel blends may be lower than other alternative fuels. They suggest that this is largely because biodiesel can be utilised in an unmodified diesel engine and that it can be transported and distributed using existing infrastructure. Interestingly, Weber (1993) notes that in the absence of government intervention soybeans are typically the best performing biodiesel feedstock variety from an economic standpoint, and in contrast to the above studies, You *et al*. (2008) find that a plant capacity of 100 000 tons of biodiesel per annum, using a continuous flow processes with an alkali catalyst, and the raw material of soybean oil, to be economically feasible.

However, Tareen *et al*. (2000) argue that the above empirical evaluations tend to ignore the stochastic nature of fuel prices, and stress that policymakers should consider price volatility effects when determining appropriate budgets for alternative fuel programmes. These authors, therefore, set about establishing an empirical link for measuring the trade-off of a relatively more expensive input, biodiesel, with lower price drift and volatility compared with a relatively cheaper but more volatile priced input, conventional diesel.

From a SA standpoint, Funke *et al*. (2009) emphasize that the cost of production of both bioethanol and biodiesel will play a significant role in terms of competitiveness, particularly in export markets. They suggest further that the fact that biodiesel is typically more costly to produce than its conventional diesel counterpart, "creates a significant challenge for the successful marketing of biodiesel in South Africa, and could hamper the successful development of a biodiesel market, especially in light of voluntary blending as stipulated in the biofuel strategy. It further indicates that the SA industry might face a serious threat if local blending mandates are imposed" (Funke *et al*., 2009: 231).

3.7 Critical Success Factors

The Worldwatch Institute (2007: 150) recognize three key economic barriers which biofuel markets face, namely (i) competition with conventional fossil fuels on a direct production cost basis (excluding environmental and/or social externalities); (ii) insufficient, unpredictable and/or inconsistent biofuel support policies; and (iii) relatively immature and unstable markets that are perceived as being highly risky long-term or high-volume investment opportunities. McCormick and Kåberger (2007) identify that the key barriers obstructing the expansion and implementation of bioenergy systems in general in the E.U. include: economic conditions; experience, know-how and institutional capacity; and supply chain co-ordination (e.g., vertical integration and partnerships). Similar implementation barriers are identified by Costello and Finnell (1998), Roos *et al*. (1999) and Rösch and Kaltschmitt (1999). Thus, McCormick and Kåberger (2007: 451) suggest that these barriers could be combated by:

- Investment grants and other incentive-based policy measures, which are critical to favourably altering economic conditions and assisting in making bioenergy systems competitive with traditional fossil fuels.

- Developing know-how and institutional capacity, which often require pilot projects to stimulate appropriate learning processes.

- Supply contracts and partnerships, which are useful in establishing functioning bioenergy systems.

While many factors are likely to influence the profitability of biofuel industries, Eidman (2007: 346) suggests that the most prominent influences will stem from: (i) the price of conventional fuels; (ii) the price of feedstocks; and (iii) government biofuel policies. Similarly, Coyle (2007) contends that the future outlook for global biofuel production will likely depend on interrelated factors including oil prices, the availability and cost of feedstocks, sustained governmental support, technological advancements that improve the feasibility of second generation biofuels, and competition from unconventional fossil fuel alternatives. In terms of governmental support, which appears non-negotiable at least in the developmental stages of biofuel ventures, Rösch and Kaltschmitt (1999: 356) recommend that "a broad and long lasting market introduction programme is required. To finance such a programme funds with sufficient finances over a significant period of time must be available".

Tiffany and Eidman (2003: 18) identified the following five factors as the most important determinants of financial success for bioethanol plants in all localities: (i) maize price; (ii) bioethanol price; (iii) natural gas price; (iv) conversion rates (e.g., litres of bioethanol per ton of feedstock); and (v) plant capacity. However, these authors note that numerous other factors, either individually or in conjunction with one another, may also influence the profitability of bioethanol ventures. These include: capital costs; percentage of debt incurred; interest rates; by-product prices; electricity costs; and federal, state, and/or local production subsidies; and other incentives. Similarly, Kenkel and Holcomb (2009: 460) emphasize the importance of long-term competitiveness with conventional petroleum-based fuels; proven and standardized technologies; consistent public policy; and appropriate business models.

Kenkel and Holcomb (2006), however, suggest that the log-run profitability of biofuel projects is driven primarily by feedstock availability, access to markets for biofuels and by-products, as well as utility costs and their availability (e.g., natural gas and electricity). Furthermore, the continued enhancement of agricultural productivity has been identified as a key success factor, particularly in preventing continued conflicts between food and biofuels (Cassman & Liska, 2007; Pingali *et al*., 2008). Tiffany and Eidman (2003) suggest further that returns to bioethanol production are often volatile, and suggest that staying power and risk management strategies are becoming increasingly crucial to the survival of such ventures, particularly during periods of high feedstock and natural gas prices. These will likely be applicable to biodiesel ventures.

Plant location is undoubtedly a critical success factor influencing the viability of biofuel ventures in general, as it has a significant bearing on the associated costs of production (Tiffany & Eidman, 2003; Kenkel & Holcomb, 2006; Amigun *et al*., 2008a, 2008b; Lambert *et al*., 2008). Tiffany and Eidman (2003) conclude that plants should ideally be located in areas of historically low feedstock prices, and have readily available, stable supplies of feedstock. Locations with cheap utilities and good access to transportation would also be preferable. Furthermore, from the perspective of small-scale, community-based biodiesel production, plants located in areas of mixed farming operations, including both crop and livestock enterprises, with large differences between high-protein meal and oilseed prices, are expected to have greater potential for success (Weber, 1993; Van Dyne *et al*., 1996; Van Dyne & Blase, 1998; Bender, 1999).

The Worldwatch Institute (2007) emphasise the need for policy-makers to take a comprehensive approach that encompasses all relevant sectors and stakeholders. These sentiments are echoed by Meyer *et al*. (2008) and Funke *et al*. (2009) from the SA perspective. Whilst this will certainly be a difficult task, the Worldwatch Institute (2007: 312) suggest that “the alternative will result in inefficient feedstock and fuel production, missed production targets, incompatibilities in the infrastructure, bottlenecks in the system, lost economic development opportunities and environmental degradation”. Finally, Amigun *et al*. (2008a) suggest that a general lack of a good understanding and application of key concepts of cost estimation, which are regarded as being critical to the success of such ventures as they directly impact profitability, are prominent barriers to the commercialisation of biofuel industries in Africa. The research methodology used in this study is presented in the next chapter.

CHAPTER 4: RESEARCH METHODOLOGY

This chapter deals with fundamental considerations in the development of a commercial crop farm model in the KZN province which may consider on-farm soybean-based biodiesel production as a potential means for value adding. These include the demarcation of the specific regions of the province that are suited to soybean production, the determination of enterprise production costs, and appropriate management practices. Particular emphasis is placed on the analysis of agricultural land rent and simulated cropping behaviour in order to evaluate the effects of alternative biodiesel policy measures and possible farmer investment behaviour. For these purposes, accurate and reliable data sources are imperative.

4.1 General Overview

Duloy and Norton (1975) note that mathematical programming used to simulate market behaviour has been a widely researched field ever since Samuelson (1952) first illustrated that an objective function exists, which, when maximised, guarantees the fulfilment of the criteria of a competitive market. Duloy and Norton (1975: 591) add that Samuelson's (1952) fundamental methodology has prominent application in empirical economic studies, "particularly in the context of agricultural planning models which may contain rather detailed supply side specifications". In this regard, Hazell and Norton (1986: 31) point out that King (1953) and Heady (1954) were among the first to report the application of linear programming in farm planning models.

Beneke and Winterboer (1973) note that linear programming is a planning method that aids decision-making when a large variety of alternative choices exist. Hazell and Norton (1986: 19) suggest that "the solution to a linear programming problem is usually a unique farm plan in terms of the optimal activity levels chosen". However, Beneke and Winterboer (1973: 4) conclude that the fundamental benefit of using linear programming as a planning method is not that it leads to an individual "foolproof" farm plan, but rather that it provides the means to quickly and effectively analyse a wide range of alternative decisions. Apland (1986: 1) adds that "the availability of efficient solution algorithms and the accessibility of computer routines which use these algorithms" makes linear programming a particularly attractive modelling alternative.

For the above-mentioned reasons it is not surprising that Burton *et al*. (1987) note that linear programming has been extensively applied in agricultural economics research and extension. From a crop farming perspective, Brink and McCarl (1978: 259; 1979:14) suggest that crop-planning models can be used for at least three purposes: (i) to aid farmers in planning their land allocations; (ii) to help farmers budget returns to investments; and (iii) to assist policy makers predict farmer responses to policy decisions. These authors note further that for all the above rationales it is important that the programming model accurately predicts land allocation distributions among crops. Thus, linear programming, using the traditional simplex algorithm, which Duloy and Norton (1975: 591) regarded as "the most powerful computational programming algorithm available", was used in this analysis to model commercial crop farms in the historically high soybean-producing regions of KwaZulu-Natal (KZN).

4.2 Development of the Baseline Model

The Biofuels Industrial Strategy of the Republic of South Africa identifies three primary field crops to be considered as feedstocks for domestic biodiesel production, namely sunflower, canola and soybeans (DME, 2007: 3). However, since sunflower and canola are grown in relatively small quantities in KZN (largely due to relatively unfavourable growing conditions) (Whitehead, 2010), soybeans are the only realistic potential biodiesel feedstock that is currently grown in large quantities in the KZN region. Subsequently, a linear programming model of a typical commercial crop farm in the historically high soybean-producing regions of KZN was developed. More specifically, these high soybean-producing areas include the Bergville/Winterton, Newcastle/Normandine, Vryheid and Midlands regions of KZN (Oates, 2010; Whitehead, 2010), as depicted in Figure 4.1. Importantly, these areas also hold the greatest potential for future expansion of soybean production in the KZN province.

The linear programming baseline model, comprising 45 rows by 50 columns, was developed using 10 years of yield, variable cost and product price data from COMBUD field crop budgets, which are compiled annually by the KZN Department of Agriculture, Environmental Affairs and Rural Development (KZNDAEARD). These income and cost budgets are generated primarily as a short-term planning aid for field crop farmers in the KZN region. These budgets explicitly assume that the yield data used in their analyses are the "long-term,

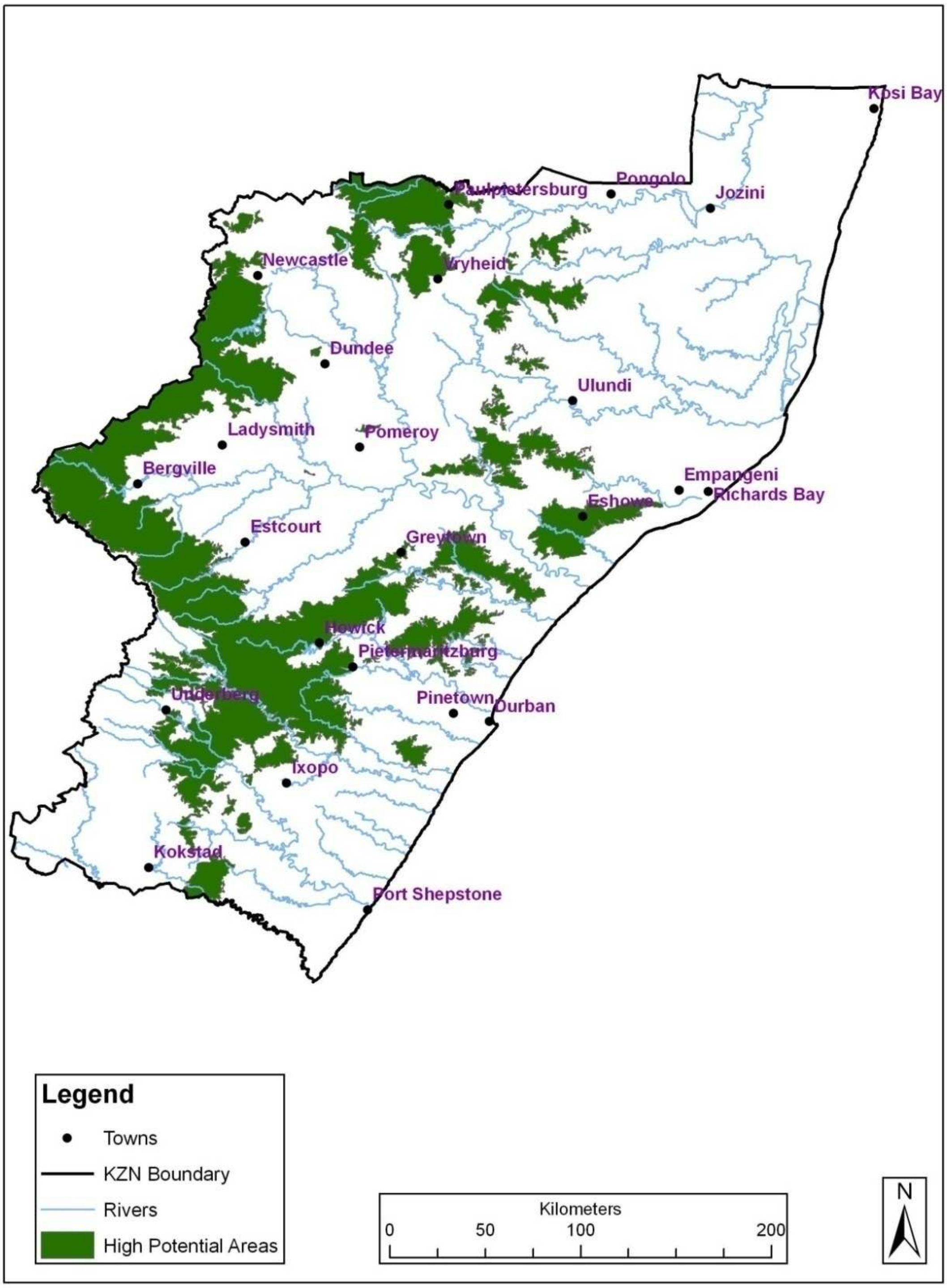

Figure 4.1: Regions in KwaZulu-Natal of Historically High Soybean Production and Significant Cropping Potential for Future Expansion of Soybeans

Source: KZNDAEARD (2010).

realistically attainable yield under normal climatic conditions, and with acceptable management practices" (KZNDAEARD, 2009: iii). The COMBUD field crop budgets are a widely accepted source of data, and Whitehead (2010) suggests that these budgets adequately reflect the average production circumstances faced by crop farmers in the KZN region.

Ford *et al*. (1995) reported that the use of historical data to calculate risk measures in programming models worked at least as efficiently as methods which used conditional information based on futures market prices. The 10 years of COMBUD data used in this analysis include the production years 2000/01-2009/10. All nominal price and cost data were adjusted to a real 2009/10 basis, using the SA Consumer Price Index (CPI).

The COMBUD field crop budgets cater for both dryland and irrigation land categories. Crops considered in the baseline model include soybeans, maize, dry beans, sorghum, groundnuts, and winter wheat. Wheat produced on arable dryland, however, was ignored in the analysis as crop farmers in the historically high soybean-producing regions of KZN, particularly in the Bergville/Winterton areas, typically only plant winter wheat under irrigation (Whitehead, 2010). Additionally, cotton was not considered in the baseline model as the total area planted to this crop in KZN has fallen markedly from approximately 6850 hectares in 2005/06 to a mere 600 hectares in 2009/10 – with no cotton planted under irrigation in the current production season (Cotton South Africa, 2010). Evidently, the typical crop farmer in the KZN region has substituted away from planting cotton. Whitehead (2010) suggests that poor product prices, less than ideal growing conditions, and institutional problems were likely contributors to the apparent failure of cotton in KZN.

Köller (2003: 3) suggests that "conventional tillage" comprises all tillage practices which leave fewer than 15 percent of crop residues on the soil surface after planting. Typically, conventional tillage incorporates the loosening of soil using a mouldboard plough, which is followed by discing and/or harrowing for seedbed preparation (Beauchamp and Hume, 1997: 644; Köller, 2003: 3). Conventional tillage practices allow for the incorporation of both lime and fertilizers into the soil, combating weed and pest outbreaks, reductions in soil compaction levels and loosening the general soil structure for the promotion of crop growth (Throckmorton, 1986: 60).

In contrast, "conservation tillage" includes any tillage and planting practice which leaves a minimum of 30 percent of crop residues on the soil surface after planting (Köller, 2003: 3).

Thus, based on this definition, conservation tillage encompasses the concept of no-till practices. In no-till systems, ploughing is eliminated and planting is achieved with direct-drill seeding equipment, resulting in minimal soil disturbance (Beauchamp and Hume, 1997: 644; Köller, 2003: 5). Thus, weed control in no-till systems is largely dependent on the use of herbicides (Throckmorton, 1986:85; Köller, 2003: 5). In the last five production seasons a notable addition to the COMBUD field crop budgets has been the inclusion of production budgets for maize and soybeans using no-till practices in the KZN region. However, since this has only been a recent inclusion in the budgets, an attempt was made to extrapolate comparable production costs, based on COMBUD estimates of conventional tillage practices, for no-till maize and soybean production for the period from 2000/01 to 2004/5, as it was necessary to have equal spans of time-series data for all crops and respective tillage practices. Chemical costs were consistently higher and diesel usage comparatively lower for the no-till system throughout the 10 year study period.

Köller (2003: 3) attributes the shift in focus of agricultural management away from intensive tillage practices toward less intensive and arguably more sustainable soil-cultivation practices, including no-till, to factors such as increasing costs of fossil fuels, adverse effects of soil erosion, and increased environmental pollution. Thus, savings associated with reductions in management requirements, lower machinery, labour, and fuel costs, as well as combating erosion have contributed to farmers moving away from conventional tillage practices (Throckmorton, 1986: 61; Beauchamp & Hume, 1997: 644).

So *et al*. (2009) report that improvements in the physical properties of soil, as direct consequence to prolonged use of no-till practices, promote increases in long-term crop productivity. Moreover, Bescansa *et al*. (2006) contend that the most significant factor influencing the wide-spread adoption of conservation tillage practices is the preservation of soil water. Therefore, since anecdotal evidence suggests that benefits such as improved levels of water infiltration, reductions in evaporation losses, and enhanced moisture retention are more likely to be prevalent on non-irrigated cropland (Thibaud, 2010; Whitehead, 2010), a conservative four percent long-term yield benefit in favour of no-till soybean and maize production was assumed for the arable dryland category. However, the respective yields for the irrigation land category between tillage practices were conservatively assumed to be equal in this analysis (Thibaud, 2010; Whitehead, 2010).

Since the COMBUD budgets did not cater for no-till production of other crops (except for maize and soybeans), it was tentatively assumed that other crops incurred identical production costs and yields under both tillage practices. Prices received were also assumed to be equal for the respective crops. Evidently, however, further research into the exact nature of the differences in production cost and yield data between no-till and conventional tillage practices is necessary for all field crops at both the regional and national level in South Africa. Nevertheless, the baseline model incorporates a discrete choice between no-till and conventional tillage practices, reflecting a realistic choice facing all crop farmers in the KZN region.

Other significant aspects of the baseline model were the farm size, crop rotation and diesel price assumptions. The constraining resource in the baseline model was the total area of cropland, in both the categories of arable dryland and irrigation. After consulting with numerous crop farmers and other industry role players, it was determined that a typical commercial crop farm in the historically high soybean-producing regions of KZN comprised of approximately 220 hectares of arable dryland and 220 hectares of irrigation land. However, as one of the overall objectives of this study was to determine the optimal farm size necessary to sustain a given biodiesel production plant in the historically high soybean-producing regions of KZN, little importance was placed on the initial farm size used in the baseline model, as this was to be varied in the analysis.

As far as crop rotations are concerned, there is broad consensus among farmers and advisors that were consulted that a 1/3 soybean – 2/3 maize rotation is most prevalent in the historically high soybean-producing regions of KZN. Moreover, the area planted to soybeans under irrigation in the summer will typically be planted to wheat in the winter, particularly in the Bergville/Winterton areas. Finally, diesel fuel was assumed to cost commercial crop farmers R6.77 per litre in the baseline model. This price was based on five years of diesel price data, adjusted to a 2009/10 basis, and accounting for the diesel subsidy of approximately R0.94 per litre farmers currently receive (Whitehead, 2010). It is important to note, however, that these assumptions are based on the typical situation among commercial crop farmers in the historically high soybean-producing regions of KZN; individual farms in these areas may well deviate from these assumptions, both in farm size and management practices. The key assumptions in the baseline model, summarised in the form of a simplified linear programming matrix, are presented in Table 4.1.

4.3 Inclusion of Risk in the Model

The presence of risk and uncertainty are typical characteristics of all farming enterprises (Low, 1974; Schurle & Erven, 1979; Kaiser & Boehlje, 1980; Hazell, 1982; Hazell & Norton, 1986; Ortmann *et al.*, 1992; Stockil & Ortmann, 1997; Pannell *et al.*, 2000). Ortmann (1985, 1988) and Tomek and Robinson (2003) note that risk can be regarded as an implicit cost of doing business. More specifically, Barry and Fraser (1976) suggest that this cost is the additional expected return, or premium, that farmers require as compensation for assuming the risk. As such, the inclusion of risk results in the marginal cost or supply curve shifting leftward, inferring that the higher the level of risk, the less famers are expected to produce at a given price level, and vice versa (Hazell & Scandizzo, 1974; Nieuwoudt *et al.*, 1988; Tomek & Robinson, 2003). Moreover, Tomek and Robinson (2003) note that empirical economic research robustly supports the view that increases in risk translate into reductions in supply, *ceteris paribus* (for example, see Brorsen *et al.*, 1987; Nieuwoudt *et al.*, 1988; Tronstad & McNeill, 1989).

Kaiser and Boehlje (1980) and Hazell and Norton (1986) suggest that risk in agriculture can be attributed to a wide variety of price, yield and resource risks (including natural disasters) which cause farmers' incomes to vary, often substantially, from one year to the next. Similarly, Ortmann *et al.* (1992) point out that farmers face a combination of variable weather patterns, volatile input and product prices, rapidly advancing technology, changing environmental regulations and changing government policies (both domestically and internationally). It is, therefore, not surprising that an abundance of evidence suggests that farmers around the world conduct their agricultural practices in a risk-averse manner (Young, 1979; Hazell, 1982; Bardsley & Harris, 1987). This view, for example, is supported by empirical evidence from Wolgin (1975), Wiens (1976), Moscardi and de Janvry (1977), Dillon and Scandizzo (1978), Binswanger (1980), Bond and Wonder (1980), and Bardsley and Harris (1987). Young (1979) contends further that farmers in developing countries are more uniformly risk-averse than comparatively wealthier farmers in developed countries.

From a South African standpoint, it has also been well-established that farmers typically behave in a risk-averse manner, and that smallholders are generally comparatively more risk-averse than commercial farmers (Ferrer *et al.*, 1997; Mac Nicol *et al.*, 2007; Ferrer *et al.*, 2009). In addition to the typical price and yield risks South African farmers face, numerous other challenges contribute to an uncertain decision making environment (Mac Nicol *et al.*, 2007). Ortmann (2005: 286) points out that these challenges include the deregulation of domestic markets in the 1990s, land reform initiatives, AgriBEE (Black Economic Empowerment in Agriculture), restrictive labour legislation and minimum wages, property (rural land) taxes, skills levies, uncertain water rights, HIV/Aids, a volatile exchange rate, and high transport and communication costs. Nieuwoudt *et al.* (1976: 487) conclude that it is imperative that risk be included in planning models in “an effort to account for the realities of dynamics within the context of a static planning model”.

Hazell (1982) and Hazell and Norton (1986: 216) note that from a theoretical standpoint the failure to incorporate risk in planning models can be expected to result in the following undesirable consequences: (i) overstatements of the output levels of risky enterprises; (ii) highly specialised cropping patterns; (iii) biased estimates of the supply elasticities of individual commodities; (iv) overestimation of the value of particular resources, such as land and irrigation water; and (v) the erroneous prediction of technology choices. Hazell and Norton (1986) suggest further that the above biases may be considerably large when modelling low-income agricultural systems, where risk aversion is expected to be most evident. For these reasons, Ortmann (1985, 1988) concludes that it is imperative to include the extent to which farmers discount their expected incomes in programming models. It is, however, important to keep in mind that although risk is undoubtedly an important factor which might encourage a decision maker to deviate from a profit-maximising alternative, it is certainly not the only force which may alter the profit criterion (Sonka, 1979).

An interesting, and somewhat contrasting, view is held by Pannell *et al.* (2000), who contend that for the various types of decision problems frequently modelled by agricultural economists, the incorporation of risk aversion often adds relatively little value to the analyses. These authors do not dispute that risk aversion influences farmer’s optimal plans, but rather suggest that the impact on farmer welfare is minimal. Pannell *et al.* (2000: 72) add that “this is likely to be true for any choice involving a continuous or approximately continuous decision variable (e.g., areas planted, input levels, stocking rates, feeding strategies and investment in futures contracts)”. They do, however, concede that it may be less true for comparatively large discrete choices (e.g., purchasing of land or large machinery).

Nevertheless, as Hazell (1971) and Kaiser and Boehlje (1980) note, conventional deterministic linear programming models explicitly ignore uncertainty. For the abovementioned reasons, this may result in unacceptable results to the farm operator, or have little relation to the decisions farmers actually make in practice (Hazell, 1971; Hazell & Norton, 1986). Subsequently, ever since Freund (1956) first developed a relatively crude farm production model that incorporated risk, marked progress has occurred in linear programming methods that permit the inclusion of risk in agricultural planning models (Hazell, 1982; Lambert & McCarl, 1985; Kaiser & Apland, 1989), at both the farm and sector levels (Hazell, 1982).

Lambert and McCarl (1985) note that maximising expected utility has been the principal theoretical foundation for risk analyses. Scott and Baker (1972) provide a brief overview of some of the more prominent developments in this field of research, and note that Markowitz (1952, 1959) first developed the expected income-variance (E-V) efficient frontier as a theoretical approach to portfolio selection. Baumol (1963) later established a criterion that significantly reduced this efficient set for the decision maker, by comparing the standard error confidence limits of expected incomes from the available portfolio combinations. While most early studies attempting to account for risk made use of quadratic programming techniques, as developed by Markowitz (1952, 1959), Hazell (1971) and Hazell and Scandizzo (1974) recommend the use of linearization techniques that allow conventional linear programming to be utilised. In this regard, McCarl and Tice (1982: 588) contend that their approach "works well for risk programming and provides superb computational advantages for large problems". For these significant benefits, as was the rationale for Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b), the methodology for incorporating risk in linear programming models first proposed by Hazell (1971), and later refined by Hazell and Scandizzo (1974), has been adopted in this study.

In this analysis possible risk-averse behaviour of farmers was catered for by maximising the criterion $E - \theta \sigma$, where E is expected income (gross margin), θ is an aggregate risk-aversion parameter, and σ is the standard deviation of income (gross margin) (Baumol, 1963; Barry & Robison, 1975; Ortmann, 1985: 96; Hazell & Norton, 1986: 91-93). Thus, the objective function treats risk (σ) as a cost that is weighted by the risk aversion coefficient (θ). The larger the θ-value, the greater weight is attached to risk and the more diversified the resulting farm plan is expected to be. A value of $\theta = 0$ implies risk-neutrality (Nieuwoudt *et al.*, 1976; Ortmann, 1985, 1988; Nanseki & Morooka, 1991), resulting farm plans will thus be mathematically equivalent to the solution of a standard linear programming model with maximised expected net returns as the objective function (Nanseki & Morooka, 1991).

Brink and McCarl (1978), Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b) note that risk associated with various enterprises is typically regarded as being reflected in the deviations of detrended gross incomes (or gross margins) per hectare from their mean. These deviations should, therefore, sum to zero for each activity (Hazell & Norton, 1986: 235). In practice, the mean absolute deviation of variance is approximated by an estimate of the standard deviation (see equation 4.2). This technique has been used in both sector (Simmons & Pomareda, 1975; Nieuwoudt *et al.*, 1976; Hazell & Scandizzo, 1977; Ortmann, 1985, 1988; Ortmann & Nieuwoudt, 1987a, 1987b) and farm level studies (Brink & McCarl, 1978, 1979; Brandao *et al.*, 1984; Lyne *et al.*, 1991a, 1991b). However, it has certainly been more prominent with sector models than with individual farm models (Hazell, 1982; Hazell & Norton, 1986: 93).

Using a combination of the approaches used by Brink and McCarl (1978: 259), Ortmann (1985: 96; 1987a: 243; 1988: 439), Ortmann and Nieuwoudt (1987a: 304; 1987b: 122), and Lyne *et al*. (1991b: 45) the basic inclusion of risk as a cost factor can thus be illustrated as follows:

$$\text{Max } L = [P'YX - C'X - \theta\,(X'\Omega\, X)^{1/2}] \qquad (4.1)$$

where P'YX is crop income, P being a vector of product prices, Y a diagonal matrix of yields per hectare, and X a vector of crop areas; C'X is production costs, C representing a vector of production costs per hectare; θ is a famer's risk aversion coefficient; Ω is a variance-covariance matrix of gross margins per hectare; and (X'Ω X) represents variance in gross margins.

The standard deviation estimate can therefore be calculated in the following manner:

$$\text{Est } (X'\Omega\, X)^{1/2} = \frac{\sqrt{\Delta}}{T} \qquad (4.2)$$

where Δ = T Π / 2(T – 1), which is regarded as a "correction factor to convert the square of the mean absolute deviation to an estimate of the population variance (assuming the population is normally distributed)" (Simmons & Pomareda, 1975: 473). In the above specification, T is the total number of periods considered, and Π is the mathematical constant.

Ortmann and Nieuwoudt (1987a, 1987b) note that the above approximation procedure captures both variances and covariances from past gross margin per hectare data for various crops, where the latter are reflected in the time series of gross margin per hectare data for the crops included in the model. Inclusion of risk in a linear programming matrix using an estimate of standard deviation is demonstrated in Table 4.2.

Table 4.2: Inclusion of Risk in a Linear Programming Matrix

Activities																
	Crop 1		Crop 2		Crop 3		......	ND1	ND2	ND3	ND4	ND5	ND6	O.5TAD	Std Dev	RHS
	Grow	Sell	Grow	Sell	Grow	Sell										
Dland (ha)																L 220
:																:
:																:
:																:
T1 (R)	DF1		DF1		DF1		......	1								G 0
T2 (R)	DF2		DF2		DF2		......		1							G 0
T3 (R)	DF3		DF3		DF3		......			1						G 0
T4 (R)	DF4		DF4		DF4		......				1					G 0
T5 (R)	DF5		DF5		DF5		......					1				G 0
T6 (R)	DF6		DF6		DF6		......						1			G 0
TDID (R)								-1	-1	-1	-1	-1	-1	1		E 0
TDCON (R)														-0.458	1	E 0
OBJ (R)	-AVC	AP	-AVC	AP	-AVC	AP	......								- θ	MAX!

Where OBJ = objective function
Dland = dryland
DF1...6 = gross margin deviations from trend for 6 years
TDID = total deviation identity
TDCON = converts total deviation to standard deviation
AVC = average variable cost per hectare
AP = average price per ton
ND1...6 = negative deviation counters
0.5TAD = half the sum of total deviations
Std Dev = estimated standard deviation
θ = risk aversion coefficient
0.458 = $2\ \Delta^{0.5} / T$, where $\Delta = T\ \Pi / 2(T - 1)$, $T = 6$ years

Hazell (1982) points out that the above criterion suffers from theoretically stringent assumptions that the producer has a quadratic utility function and/or that farm income is normally distributed. However, Tsiang (1972) argued that the criterion has computational appeal and provides a close approximation to more desirable decision criteria, particularly if the risk taken is small relative to the producer's total wealth. Hazell (1982) notes further that this condition may be satisfied on commercial farms (or alternatively on small farms where substantial income arises from off-farm sources), although it may not hold true for small subsistence farms in developing countries. However, Lambert and McCarl (1985) contend that whilst the above-mentioned assumptions have been repeatedly debated, this has not hampered widespread application.

4.4 Model Validation

McCarl and Apland (1986: 155) note that model validation is an imperative component of any empirical economic analysis, since “a model cannot be utilised with confidence unless it is considered a valid portrayal of the system modelled”[4]. Brink and McCarl (1979) suggest that, in the context of crop planning models, the ability of the model to adequately predict cropping patterns may be of greater interest than its capacity to predict farm income and farm income changes (for example, as a result of a new investment). Similarly, Ortmann (1985, 1988) contends that before a model can be used to evaluate various policy measures, model outputs should be compared with actual cropping behaviour and prices. Furthermore, this will allow an additional means to check the accuracy of cost data (Nieuwoudt, 1980; Ortmann, 1985, 1987b, 1988). McCarl and Apland (1986) note that whilst approaches to model validation can vary widely, a systematic approach will allow for a semi-objective means to evaluate the strengths and shortcomings of a given model. These authors conclude that model validation requires measuring how adequately the model serves its intended purpose.

When using cropping models which incorporate risk by maximising the criterion $E - \theta\ \sigma$, Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b) note that the sensitivity of the model can be determined by testing various values of θ in successive optimisations. Thus, the θ value that gives solutions that most closely resemble actual cropping behaviour and prices can thereafter be used in the model to analyse various alternative choices farmers may face and an assortment of policy measures. In addition to predicting cropping behaviour, Ortmann (1985, 1988) contends that of particular importance is the effect of θ values on the shadow price of land. Generally, these show decreases with increasing θ values. At the theoretical optimum θ value, however, the shadow price of land per hectare should emulate actual land rents observed in the research area. Similarly, Nieuwoudt *et al*. (1976) placed some significance on the influence θ values had on the shadow prices of peanut acreage allotments in various regions in the USA. The fact that θ values can be easily manipulated when using the criterion $E - \theta\ \sigma$ provides the modeller with a relative degree of flexibility. Thus, Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b) conclude that the θ coefficient can essentially be regarded as a fine-tuning device.

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[4] McCarl and Apland (1986:155) define validation as “exercises designed to determine whether there is a sufficient relationship between modelled behaviour and observed behaviour such that the model user is content to use a model as a predictor”.

Previous empirical analyses include that of Simmons and Pomareda (1975), who found, in their simulation of Mexican vegetable production and exports, that a value of θ = 0.5 gave the best simulations for export vegetables, chickpeas, beans, and wheat. Nieuwoudt *et al*. (1976) established that a value of θ = 2 provided the best results when they modelled peanut production in the U.S. Hazell and Scandizzo (1977) found that their model of agricultural production at a subsector level in Mexico provided the best fit with a value of θ = 1. Brink and McCarl (1978), in their study of U.S. Cornbelt farmers, reported that a value of θ = 0.23 as providing the minimum absolute deviation between actual and predicted cropping patterns. Similarly, Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b), in an analysis of the South African sugar industry, ascertained that a value of θ = 0.25 gave the most meaningful results in terms of predicting cropping patterns and emulating actual land rents. Brandao *et al*. (1984) reported θ values of 0.9 and 1.2 for landlords and tenant farmers in Brazil. Similarly, Lyne *et al*. (1991a) used a θ value of unity in their study of small-scale farmers in South Africa. However, while a comparison of θ values with past research is often interesting, Brink and McCarl (1978) warn that such coefficients are not necessarily directly comparable due to possible differences in risk modelling (e.g., calculation of deviations), crop coverage, and aggregation.

Despite the θ coefficient often being referred to as a risk aversion coefficient in farm or sector models, Ortmann (1985, 1988) notes that it is questionable whether θ in fact measures aggregate risk aversion. Hazell (1982: 386) points out that there are two major criticisms of using θ as a fine-tuning device to validate the model: (i) θ may be biased by model misspecification and data errors; and (ii) if farmers have access to risk-sharing institutions (e.g., crop insurance and/or futures markets), then their farm planning decisions will not adequately reflect their real risk preferences. Therefore, if such risk-sharing institutions are omitted from the model, the θ value will likely be underestimated. Similarly, Brink and McCarl (1978: 260) note that attributing all of the difference between plans to risk alone "would embody strong assumptions", as the current actual farm practices will also be influenced by other enterprise mixes (such as livestock), or forward commitments (such as contracts for future delivery). Ortmann (1985: 109), however, adds that it may be as or even more essential to capture the effects other than risk in the model. Thus, Nieuwoudt *et al*. (1976), Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b) placed very little significance on the θ value, which was used only to fine-tune and improve the predictive capacities of their models. As such, relatively little can be concluded about farmers' levels of risk aversion in the sectors these authors studied.

4.5 Agricultural Land Rent and the Shadow Price of Land

Land use and land value have been prominent interests in the agricultural economics discipline for many years (Robinson *et al*., 1985; Just & Miranowski, 1993; Miller & Platinga, 1999). However, despite the renting of agricultural land being evident ever since the development of "organised land settlements" (Barlowe, 1986: 131), Ortmann (1987b) notes that the economic interpretation of land rent has been a somewhat contentious issue amongst economists for a number of years. Goodwin (1977: 351) defines economic rent as "that price that a resource is paid in excess of the price that is necessary to keep it from transferring to some other use". In more formal economic terms, Ortmann (1987b) regards rent as the return to a unique factor of production, such as land, over and above its opportunity cost. Nieuwoudt (1976: 194) points out that any factor of production with a positive-sloping supply captures rent; and since rent is a residual, it does not determine price, but rather is determined by it. Thus, since the supply of agricultural land has a positive slope (Bullock *et al*., 1977), the economic deduction is that agricultural land captures rent. From an agricultural perspective, therefore, rent can be regarded as the return to land (including fixed improvements) once both implicit and explicit costs of production have been accounted for (Ortmann, 1987b).

A principal feature of popular land value literature is the assumption that the value of land is equal to the discounted present value of expected future returns from the land (Robinson *et al*., 1985; Burt, 1986; Goodwin *et al*., 2003). For example, Krenz (1975) points out that agricultural land is worth only what farmers are willing to pay for it, which is a function of expected profits from future production. However, Clark *et al*. (1993) and Chavas and Thomas (1999) contend that simple capitalization formulas sometimes fail to adequately represent observed land prices, as factors other than expected income streams, such as levels of risk aversion (Just & Miranowski, 1993; Chavas & Thomas, 1999), transaction costs (Chavas & Thomas, 1999), or various other speculative forces (Melichar, 1979; Falk, 1991) can influence land prices. Moreover, Goodwin *et al*. (2003: 750) highlight that the standard capitalization model is based on expected returns, when expected returns are actually "inherently unobservable". Similarly, Krause and Brorsen (1995) established that risk is a significant factor explaining the variability in the cash rental value of agricultural land. Their results suggest that as risk increases, the rental value of agricultural land falls.

Lence and Mishra (2003: 760) contend that “farmland values are intrinsically associated with the economics of the farm sector”. A relatively straightforward measure of the return attributed to land is the cash rent a tenant would pay to acquire control of the land in question (Robinson *et al*., 1985; Krause & Brorsen, 1995). Another possible measure is residual income to land (Krause & Brorsen, 1995). However, Alston (1986: 5) contends that the residual income to land measure suffers from significant measurement problems, “particularly related to imputing costs for capital equipment and management”, and erroneously treats land as the residual claimant for agricultural production (Krause & Brorsen, 1995). Nevertheless, Alston (1986) suggests that cash rent data corresponds relatively closely to the concept of expected rent. Similarly, Falk (1991) established that farmland rents and prices were highly correlated, but that land price movements were significantly more volatile than rent movements. However, Clark *et al*. (1993) point out that Falk (1991) did not find the farmland rent and price time series to be unambiguously co-integrated.

Nevertheless, Nieuwoudt (1980) and Ortmann (1987b) argue the case that land rent data provides an adequate indication of the average profitability of an agricultural enterprise after accounting for all costs of production, including management and production risks. Furthermore, Ortmann (1987b: 251) contends that “the fact that relatively few farms in South Africa are rented does not negate the value of rent data as a proxy for the profitability of a crop”.

4.6 A Comparison of Model Solutions with Typical Land Rental Rates and Observed Cropping Behaviour in the Soybean-Producing Regions of KwaZulu-Natal

Before the model can be utilised to evaluate alternative biodiesel policies and possible farmer investment behaviour, simulated results should be compared with the current observed agricultural situation in the historically high soybean-producing regions of KZN. This was achieved by examining the relationship between the simulated shadow price of land per hectare and actual rental rates of agricultural land per hectare, as well as comparing predicted cropping behaviour with observed trends in the region. Sensitivity of the optimal solution was determined by using successive values of θ. The value of θ which yields estimates that most closely resemble observed trends in rental rates of agricultural land and cropping behaviour in the soybean-producing regions of KZN will thereafter be used to study various biodiesel policy measures and their impacts on farmer investment behaviour. Thus, as suggested by Nieuwoudt *et al*. (1976), Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b), θ in essence was used to fine-tune the model.

Estimates of the value of agricultural land with cropping potential, for both dryland and irrigation land categories, in the high soybean-producing regions of KZN were obtained from various farm property evaluators, property agents, and agricultural divisions of commercial banks. These estimates were based on recent comparable farm sales, actual farm financial records, as well as experience in the agricultural industry in KZN. The market value estimates for arable dryland across the study areas ranged between R 8 000 per hectare and R 25 000 per hectare, whilst the irrigation land value estimates ranged from R 20 000 per hectare to as much as R 45 000 per hectare. Clearly, market values of agricultural land with cropping potential vary markedly by region in KZN. Nevertheless, the numerical average of these estimates of land values were approximately R 15 000 per hectare and R 35 000 per hectare for dryland and irrigation land, respectively. Estimates of rental rates for agricultural land with cropping potential in the historically high soybean-producing regions of KZN ranged from four percent to as high as nine percent. However, the average estimated rental rate was between four and five percent. The simulated shadow prices of land at various values of θ are presented in Table 4.3. As anticipated, these values decrease with an increase in the value of θ, as greater weight is placed on risk – which is an implicit cost of doing business (Ortmann, 1985, 1988; Tomek & Robinson, 2003).

Previous estimates of agricultural land rental rates in South Africa include the study by Nieuwoudt (1980), who reported a capitalization rate of 5.4 percent for agricultural land in South Africa for 1978/79. Similarly, Ortmann (1985, 1987b) found the capitalization rate for South African sugarcane land, inclusive of cane quotas, to be 6.3 percent and between four and five percent for land only. In contrast, Poray (1983) estimated a comparatively lower rate of 3.2 percent for agricultural land in South Africa for 1982. To the author’s knowledge, no other recent empirical estimates for SA agricultural land rental rates are available.

Table 4.3: Average Values and Estimated Rental Rates for Arable Dryland & Irrigation Cropping Land in the Soybean-Producing Regions of KwaZulu-Natal (2009/10 = 100)

	Land Category	Land Value (R/ha)	Estimated Rent (R/ha)	Estimated Rent/Land Value (%)	Average Estimated Rental Rate (%)
θ = 0.0	Dryland	15 000	3033.83	20.23	20.35
	Irrigation	35 000	7166.39	20.48	
θ = 0.5	Dryland	15 000	2477.62	16.52	16.38
	Irrigation	35 000	5687.13	16.25	
θ = 1.0	Dryland	15 000	1921.42	12.81	12.42
	Irrigation	35 000	4207.87	12.02	
θ = 1.5	Dryland	15 000	1365.22	9.10	8.45
	Irrigation	35 000	2728.62	7.80	
θ = 2.0	Dryland	15 000	809.01	5.39	4.48
	Irrigation	35 000	1249.36	3.57	

A study of the estimated average rental rates for agricultural land in the historically high soybean-producing regions of KZN in the model where θ = 2 indicates that these appear to be the most realistic simulated rental figures, as they compare favourably with actual rental rates observed in the industry and are broadly in line with historical SA trends. It should be noted that agricultural land rentals, and hence land values, tend to be farm specific, depending on many inter-related factors such as soil fertility, water availability, management practices and subsequent yield/profit potential, the total parcel size of land available, proximity to markets, and infrastructure (Vitaliano & Hill, 1994; Barry *et al*., 2000: 345). However, the rental rates are expected to be relatively similar, typically in the region of four to five percent in the SA case.

By comparison, average cash rental rates for all cropland in the U.S. during 2009 were approximately 3.4 percent (USDA, 2009), and have fluctuated around this rate over the last five years. However, areas of historically higher cropping production appear to command higher rental rates. For example, the U.S. Cornbelt's average cash rental rate for cropland ranged from approximately 3.8 to 4.4 percent between 2005 and 2009, with the mean for this period being approximately four percent. When evaluating the numerical average of both land categories in the historically high soybean-producing regions of KZN in the model where θ = 2, it is interesting to note that these estimates are relatively similar to recent average cash rental rates of cropland observed in the U.S. Cornbelt region, as reported by the USDA (2009).

In addition to the cash rental rates, it is also of interest to examine the effects of increasing θ values on predicted cropping behaviour in the soybean-producing regions of KZN. Table 4.4 presents the predicted areas planted to the respective summer and winter crops under successive θ values. As anticipated, the larger the θ value, the greater weight is attached to risk and the more diversified the resulting farm plan. However, given the relatively stringent assumptions made in the baseline model (e.g., available land, crops considered, crop rotation constraints, etc.) there is unlikely to be considerable variation in simulated cropping patterns. Moreover, for the baseline model developed in this analysis, θ may also capture some fixed costs associated with planting the various field crops under the respective tillage practices.

Table 4.4: Comparisons of Predicted Cropping Patterns at Various θ Values in the Soybean-Producing Regions of KwaZulu-Natal (2009/10 = 100)

Particulars	Model Solutions for									
	θ = 0		θ = 0.5		θ = 1		θ = 1.5		θ = 2	
	Dryland	Irrigation	Dryland	Irrigation	Dryland	Irrigation	Dryland	Irrigation	Dryland	Irrigation
Tillage Practice										
Conventional	No	No	No	No	No	No	No	No	No	No
No-Till	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Summer Crops										
Soybean (ha)	73	73	73	73	73	70	70	70	70	70
Maize (ha)	147	147	147	147	147	140	140	140	140	140
Dry Beans (ha)	0	0	0	0	0	10	10	10	10	10
Sorghum (ha)	0	0	0	0	0	0	0	0	0	0
Groundnuts (ha)	0	0	0	0	0	0	0	0	0	0
Total (ha)	220	220	220	220	220	220	220	220	220	220
Winter Crops										
Wheat (ha)	0	73	0	73	0	70	0	70	0	70
Total (ha)	0	73	0	73	0	70	0	70	0	70
Objective Function Value (R)	2 244 047		1 796 246		1 357 672		925 897		497 872	

In sector models, correlations between actual and predicted cropping areas can be statistically analysed, and the θ value which yields the closest fit to actual cropping areas would be selected to study further policy measures (Nieuwoudt *et al.*, 1976; Ortmann, 1985, 1988; Ortmann & Nieuwoudt, 1987a, 1987b). In contrast, at farm level models of this nature, where a typical farm size was selected as the baseline model, it is important that the cropping patterns predicted by the baseline model are in line with the planting activities of commercial crop farmers in the soybean-producing regions of KZN.

In the last decade commercial crop farmers in the historically high soybean-producing regions of KZN have moved progressively away from conventional tillage practices in favour of zero or minimum tillage (Whitehead, 2010). All successive model optimizations depict this preference of no-till over conventional tillage on a typical commercial crop farm in the high soybean-production regions of KZN. However, some farmers in these areas may still have a preference for conventional tillage systems. Additionally, the dominant crops planted in these regions of the KZN province have consistently been maize, soybeans and irrigated winter wheat. Dry beans are planted to a lesser extent by some farmers in the historically high soybean-producing regions of KZN, particularly the Bergville/Winterton area, but usually not on a consistent or annual basis. Dry beans, however, are historically a more common means to diversify cropping enterprises in the KZN region than sorghum and/or groundnuts (Whitehead, 2010). The predicted dominance of maize, soybeans, and irrigated winter wheat is evident in Table 4.4 as the areas planted to these crops are relatively stable in all successive model solutions. From θ values greater than unity, however, dry beans are drawn into the predicted solution as a means of crop diversification. This, however, is not considered to be unrealistic for the historically high soybean-producing regions of KZN (Whitehead, 2010).

Generally, all optimisations perform comparably in terms of predicting cropping behaviour on a typical commercial crop farm in the soybean-producing areas of KZN. However, the model where $\theta = 2$ clearly outperformed the others in terms of simulating observed rental rates for cropland in these regions. For this reason, $\theta = 2$ was selected to use in the baseline model, upon which alternative biodiesel policies and possible farmer investment behaviour will be based. Interestingly, Nieuwoudt *et al*. (1976) utilised the identical value of θ when they modelled peanut production in the U.S.

Similar to Nieuwoudt *et al*. (1976), Ortmann (1985, 1988) and Ortmann and Nieuwoudt (1987a, 1987b), no attempt will be made to draw conclusions about the level of risk-aversion among commercial crop farmers in the soybean-producing regions of KZN. This is due to the fact that θ may capture numerous other factors such as model misspecifications (Hazell, 1982). These may include incorrect constraints, incomplete or inaccurate data, different objective functions and risk sharing activities - in addition to levels of risk aversion (Ortmann, 1985, 1988). Thus, θ was used only to fine-tune the predictive capacity of the model.

CHAPTER 5: AN ECONOMIC EVALUATION OF POTENTIAL ON-FARM BIODIESEL PRODUCTION ON COMMERCIAL CROP FARMS IN THE SOYBEAN-PRODUCING REGIONS OF KWAZULU-NATAL

In the previous chapter the fundamentals of the baseline commercial crop farm model in the historically high soybean-producing regions of KZN was developed and validated. This chapter expands upon this model to evaluate potential on-farm biodiesel production using soybeans as the feedstock. It also presents results on the economic feasibility of on-farm soybean-based biodiesel production in the study regions. The influence of key solution variables on the viability of these ventures is analysed in detail, followed by some conclusions and recommendations.

5.1 Development of the Baseline On-Farm Biodiesel Production Model

The baseline model, where $\theta = 2$, discussed in the preceding chapter was used as the basis to develop a mixed integer linear programming model, comprising approximately 55 rows by 70 columns, in order to analyse the economic feasibility of soybean-based biodiesel production on commercial crop farms in regions of KZN with historically high soybean production and significant cropping potential for future expansion of soybeans[5]. Data on the associated costs of purchasing, installing and operating various capacities and qualities of both oil extrusion and batch processing biodiesel plants were obtained from domestic and international technology suppliers. The economic evaluation of batch processing biodiesel plants is, therefore, an exploration of the recommendations of Amigun *et al.* (2008a), who postulate that the comparatively lower capital requirements (relative to continuous flow biodiesel plants), as well as the ability to regulate production within demand results in batch processes being well suited to small-scale biodiesel production operations, and thus to the African continent. Moreover, these authors point out that lower capital outlays may be a means of combating risks in biodiesel industries in the event that government energy policies are both uncertain and unpredictable. Against a backdrop of recent criticisms of the SA biofuels industrial strategy and limited local research, an analysis of batch biodiesel processors' appropriateness in the KZN region is well justified.

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[5] The full linear programming matrix for the baseline on-farm biodiesel production model is available from the author

In an effort to remove bias, quotations received from six different technology suppliers were used to average capital expenditure cost estimates for two representative oil extrusion plants of different capacities, yet comparable qualities. Similarly, quotations from six technology suppliers were used to estimate average capital expenditure costs for five batch processing biodiesel plants of differing quality and capacity. Biodiesel plants were subsequently classified into broad quality groups, “high-tech” and “low-tech”, based on the composition and longevity of their respective components. Hence, estimates of the associated capital costs for the biodiesel processing plants are believed to be relatively more representative of the current SA industry than recent studies such as Nolte (2007), who utilised only one international technology supplier.

Fixed costs for the respective plants were annualised using the standard capital recovery approach (Gittinger, 1982; Monke & Pearson, 1989), assuming a real discount rate of five percent, zero salvage value, and an economic life of 15 years for the oil extrusion plants and “high-tech” biodiesel plants. Similarly, an economic life of five and 20 years were assumed for “low-tech” biodiesel plants and buildings, respectively. Annual capacities were based on the assumption of a six hour working day, for 240 days per annum (Lagrange, 2010).

There appears to be consensus among market participants, technology suppliers and industry specialists that variable extrusion costs of plant oil are in the region of R250.00 and R300.00 per ton; a similar conclusion was reached by Nolte (2007). However, the relevant parties consulted indicate that it is important to account for additional variable costs such as transport and storage, which increase variable costs quite considerably. Thus, based on these consultations, the variable (operating) cost per litre of soybean oil was assumed to be R3.75 in the baseline potential on-farm biodiesel production model. Similarly, the average variable cost to produce a litre of biodiesel from soybean oil was assumed to be R2.00, comprising primarily of chemical costs. These are believed to be relatively conservative estimates of the associated production costs for the respective production processes. Table 5.1 provides a summary of the baseline assumptions regarding capacity, annual fixed costs, and variable (operating) costs for the respective oil extrusion and batch processing biodiesel plants.

Table 5.1: Key Plant Assumptions in the On-farm Biodiesel Production Model (2009/10 = 100)

	Oil Extrusion Plant 1	Oil Extrusion Plant 2	Biodiesel Plant 1 (Low-Tech)	Biodiesel Plant 2 (Low-Tech)	Biodiesel Plant 3 (High-Tech)	Biodiesel Plant 4 (High-Tech)	Biodiesel Plant 5 (High-Tech)
Annual Capacity (Litres)	90 720	259 200	48 000	96 000	360 000	960 000	1 920 000
Annualised Fixed Cost (Rand)	59428	158475	21656	36752	61309	108099	187966
Variable Cost / Litre Product (Rand)	3.75	3.75	2	2	2	2	2

The DME (2006: 109) suggests that one ton of soybean produces 171.4 litres of biodiesel, with additional by-products being 0.680 tons of soybean oilcake, and 0.215 tons of glycerine. These figures appear to be based on the assumption that soybeans have an 18 percent oil content (e.g., Rajagopal & Zilberman, 2007: 102), and approximately a 95 percent conversion rate efficiency factor from soybean oil to biodiesel. The oil content and efficiency factor assumptions, as proposed by the DME (2006), may not be unrealistic, but they may be overly optimistic as some industry participants indicate that using traditional oil extrusion technology a comparatively lower yield of approximately 120 litres of soybean oil per ton of soybeans can be expected, as roughly six percent of the oil remains in the soybean oilcake (Bullock, 2010; Fichart, 2010). Nevertheless, in order to be consistent with the apparent thinking of current South African policy makers, conversion ratios for soybean-based biodiesel and associated by-products used in this analysis are based on those proposed by the draft National Biofuels Strategy (DME, 2006). These conversion ratios were converted to a tons per litre basis (see Table 5.2).

In contrast, studies by the Bureau for Food and Agricultural Policy (BFAP) (2008), Meyer *et al.* (2008) and Funke *et al.* (2009) used more favourable conversion and extraction rates of approximately 194 litres of biodiesel and 800 kilograms of oilcake per ton of soybeans, respectively. At this juncture, it is important to highlight that a significant difference in the above research and this study is that these conversion ratios are applicable to large-scale continuous flow biodiesel plants, as well as utilising the more efficient hexane oil extrusion process. The focus of this study, however, is small-scale batch processing biodiesel plants and traditional oil extrusion systems – both of which are typically less capital intensive, yet not as efficient processes as those used in the studies mentioned above. Nevertheless, evidence reflecting gains from economies of scale in the biodiesel production process have been mixed (Bender, 1999; Eidman, 2007; Amigun *et al*., 2008a, 2008b).

There is broad consensus that the sale and/or productive use of by-products contribute significantly to the economic viability and competitiveness of biodiesel plants (Coyle, 2007; Amigun *et al*., 2008b). Moreover, it is believed that the relatively high market value of soybean oilcake in particular may result in soybeans having the greatest potential as a first generation biodiesel feedstock (Bender, 1999; Meyer *et al*., 2008). However, market prices of soybean oilcake in South Africa are highly volatile, compounded by the fact that the country has historically been a net importer of this commodity (Funke *et al*., 2009; Protein Research Foundation, 2010). Funke *et al*. (2009: 234) point out further that domestic oilcake prices are subsequently highly dependent on international prices and domestic supplies are directly dependent on the international market, as well as international policy developments – such as biofuel policies in the U.S. and E.U. Accordingly, a similar situation exists for the SA soybean oil market.

The long-term (10 year) KZN average soybean producer price estimated in the baseline model was R3039 per ton (2009/10 = 100). Under the 2009/10 price relationships (e.g., exchange rates, transaction costs, etc.) assumed in the BFAP model, this would result in simulated prices of approximately R3738 and R9180 per ton for soybean oilcake and soybean oil, respectively[6]. This translates to a price of approximately R8.44 per litre of soybean oil. Thus, given the scarcity of sufficient spans of time-series data for these commodities, particularly soybean oil, these prices were assumed in the baseline on-farm biodiesel production model. By comparison, industry participants and technology suppliers suggest that under current (2009/10) market conditions, biodiesel sells on average at between R6.50 and R6.60 per litre. The BFAP model predicts similar biodiesel prices (Funke, 2010), lending more credibility to previous price estimates. Thus, a biodiesel selling price of R6.55 per litre was assumed in the baseline on-farm biodiesel production model.

Internationally, the crude glycerine by-product currently has a very limited market (Eidman, 2007). The same appears to be true in the South African context, where local industry participants and technology suppliers report that under current (2009/10) market conditions crude glycerine typically sells for approximately R1.00 per kilogram. However, anecdotal evidence advocates further that the difficulties in selling this by-product, given current uses

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[6] These are based on the author’s calculations on BFAP model solutions received from Funke (2010).

of glycerine, infer that this price is more or less at its upper limit and would likely decrease with an increase in the supply of glycerine, as consequence to increased local biodiesel production. Nevertheless, in order to reflect current (2009/10) market conditions, a market price of R1000 per ton was assumed for crude glycerine in the baseline on-farm biodiesel production model. An additional novel feature of this model was the allowance made for the possible on-farm use of biodiesel for the planting/harvesting requirements of the respective field crops. Key features of the baseline potential on-farm biodiesel production model are summarised in the form of a simplified linear programming matrix (see Table 5.2).

Table 5.2: A Partial Mini-Tableau of the Baseline Model (2009/10 = 100)

	Soybeans				Oil-Extrusion		Biodiesel		Sell	Sell	Sell	Sell	Use	Buy	RHS
	Dryland	Irrigated			Plant 1		Plant 2								
	Soygrow	Soygrow	Soysell	Soybuy	GIN	Operation	GIN	Operation	Soy oil	Biodiesel	Oilcake	Glycerine	Biodiesel	Diesel	
	(ha)	(ha)	(ton)	(ton)		(litre)		(litre)	(litre)	(litre)	(ton)	(ton)	(litre)	(litre)	
Dryland (ha)	1														L 220
Irrigation (ha)		1													L 220
Transfer (ton)	-2.08	-3.5	1	-1		0.00555556									L 0
OP1 capacity (litre)					-90720	1									L 0
BP1 capacity (litre)							-48000	1							L 0
Soy oil (litre)						-1		1	1						L 0
Conversion (litre)								-0.95		1			1		L 0
Oilcake (ton)						-0.0037778					1				L 0
Glycerine (ton)								-0.001254				1			L 0
Dieseluse (litre)	20	35											-1	-1	L 0
Objective (R)	-3657	-5758	3039	-3439	-59428	-3.75	-21656	-2.00	8.44	6.55	3738	1000		-6.77	MAX!

5.2 Baseline On-Farm Biodiesel Production Results

The baseline model results reflect the current situation facing commercial crop farmers in the historically high soybean-producing regions of KZN, based on the macroeconomic assumptions and optimistic conversion ratios as presented in the previous section. Table 5.3 provides a summary of the key solution variables for the baseline optimisation, with θ = 2.

Table 5.3: Optimistic* On-Farm Biodiesel Production Baseline Results (2009/10 = 100)

Cropping Behaviour	Dryland	Irrigation		**Investment Behaviour**	
Tillage Practice				**Oil Extrusion**	
Conventional	No	No		Plant 1	Yes (1)
No-Till	Yes	Yes		Plant 2	No
Summer Crops					
Soybean (ha)	70	70		Sell Soybean Oil (litres)	70 308
Maize (ha)	140	140		Sell Soybean Oilcake (tons)	266
Dry Beans (ha)	10	10			
Sorghum (ha)	0	0		**Biodiesel**	
Groundnuts (ha)	0	0		Plant 1 (Low-Tech)	No
Total (ha)	220	220		Plant 2 (Low-Tech)	No
Winter Crops				Plant 3 (High-Tech)	No
Wheat (ha)	0	70		Plant 4 (High-Tech)	No
Total (ha)	0	70		Plant 5 (High-Tech)	No
Buy Soybeans (tons)	0			Sell Biodiesel (litres)	0
				Sell Glycerine (tons)	0
Objective Function Value (R)	573 980				

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

It is important to note that the predicted cropping behaviour is identical to that presented in Table 4.4. As far as simulated potential farmer investment behaviour is concerned, under the baseline assumptions the smallest oil extrusion plant (Plant 1) is drawn into the optimum solution. Consequently, an increase in the objective function value relative to the results reported in Table 4.4 occurs, which reflects farmers behaving in a profit maximising manner by pursuing oil extrusion ventures. The baseline solution, therefore, estimates that approximately 70 308 litres of soybean oil and 266 tons of soybean oilcake will be sold. Importantly, however, no combination of oil extrusion and biodiesel plants are drawn into the optimum solution for an individual commercial crop farm in these regions. As such, no biodiesel production occurs.

However, this solution is highly sensitive to both the soybean oil price and soybean oilcake price. For example, in the event that the prices of soybean oil and soybean oilcake decrease by R1 per litre and R50 per ton, respectively, the smallest oil extrusion plant is no longer drawn into the optimum solution. Accordingly, neither of these by-products are sold and once again no biodiesel production occurs in these regions, as presented in Table 5.4. Not surprisingly, since no oil extrusion or combination of oil extrusion and biodiesel plants are drawn into this solution, the objective function value reverts back to that presented in Table 4.4 (R497 892).

Table 5.4: Optimistic* Baseline Results, assuming Decreased Soybean Oil (R7.44/litre) and Soybean Oilcake Prices (R3688/ton) (2009/10 = 100)

Investment Behaviour			
Oil Extrusion		**Biodiesel**	
Plant 1	No	Plant 1 (Low-Tech)	No
Plant 2	No	Plant 2 (Low-Tech)	No
		Plant 3 (High-Tech)	No
		Plant 4 (High-Tech)	No
		Plant 5 (High-Tech)	No
Sell Soybean Oil (litres)	0	Sell Biodiesel (litres)	0
Sell Soybean Oilcake (tons)	0	Sell Glycerine (tons)	0
Objective Function Value (R)	497 872		

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

The fact that biodiesel is not produced under either of these scenarios is not surprising, given that soybean oil is currently a higher-value product. Moreover, net variable costs per litre are comparatively lower than those of biodiesel production. This clearly emphasises the need for intervention should the SA government realistically wish to pursue domestic soybean-based biodiesel production. Furthermore, given that the markets for both soybean oil and soybean oilcake are highly volatile, and the sensitivity of the baseline model to these two commodity prices, which are closely related, the observed trend of individual crop farmers (not only in the KZN region) typically not establishing oil extrusion plants, let alone soybean-based biodiesel plants, may reflect general preferences in avoiding these relatively riskier enterprises (Funke, 2010; Hislop, 2010).

Nevertheless, in an attempt to quantify the level of government intervention necessary to draw biodiesel production into the optimum linear programming solution, the original baseline price assumptions are maintained. This may not be overly unrealistic given that South Africa is a net importer of both soybean oil and soybean oilcake. As such, their respective prices are already likely to be relatively close to import parity levels. Thus, successive optimisations of the baseline model with incremental increases in the biodiesel price were analysed to establish the minimum biodiesel price required to draw biodiesel production into the solution. Table 5.5 presents a summary of these successive optimisations using the optimistic soybean oil conversion ratios.

Table 5.5: Optimistic[*] Baseline Results under Various Farm-Level Biodiesel Prices, assuming Soybean Oil = R8.44/litre and Soybean Oilcake = R3738/ton (2009/10 = 100)

Investment Behaviour						
Biodiesel Price (R/litre)	6.55	7.55	8.55	9.55	10.19	10.72
	(Baseline)					
Oil Extrusion						
Plant 1	Yes (1)	Yes (1)	Yes (1)	Yes (1)	Yes (1)	Yes (1)
Plant 2	No	No	No	No	No	Yes (7)
Sell Soybean Oil (litres)	70 308	70 308	70 308	70 308	0	0
Sell Soybean Oilcake (tons)	0	0	0	0	343	7197
Biodiesel						
Plant 1 (Low-Tech)	No	No	No	No	No	No
Plant 2 (Low-Tech)	No	No	No	No	Yes (1)	No
Plant 3 (High-Tech)	No	No	No	No	No	No
Plant 4 (High-Tech)	No	No	No	No	No	No
Plant 5 (High-Tech)	No	No	No	No	No	Yes (1)
Sell Biodiesel (litres)	0	0	0	0	86184	1809864
Sell Glycerine (tons)	0	0	0	0	114	2390
Buy Soybean (tons)	0	0	0	0	113	10193
Objective Function Value (R)	573 980	573 980	573 980	573 980	576 113	638 427
Implicit Subsidy (R/litre)	0.00	1.00	2.00	3.00	3.64	4.17

[*] Assumes a yield of 180 litres of soybean oil per ton of soybeans

Given the underlying assumptions in the baseline model, the minimum biodiesel price necessary for biodiesel production to be drawn into the optimum solution is R10.19 per litre, implying a subsidy of R3.64 per litre. Subsidisation of the biodiesel price up to the soybean oil price (R8.44/litre) would subsequently be insufficient for farmers in the historically high soybean-producing areas of KZN to establish and operate a batch processing biodiesel plant. Therefore, these preliminary results provide evidence that supports the notion of Funke *et al.* (2009), who contend that the incentives and commitments outlined by the SA biofuels industrial strategy (DME, 2007) are inadequate to both establish and sustain a domestic biodiesel industry.

At a biodiesel price of R10.19 per litre on-farm soybean-based biodiesel production in these areas of KZN is so viable that it actually warrants farmers to buy in soybeans to supplement their own production. In this scenario the optimum solution utilises a combination of the smallest oil extrusion plant (Plant 1) and the largest Low-Tech biodiesel plant (Plant 2). The ability of this model to establish such optimum combinations is envisioned to assist both policy makers and technology suppliers in promoting the “most viable” plants of a given capacity and quality. Interestingly, the minimum biodiesel price required to draw in the High-Tech biodiesel plants into the optimum solution is R10.72 per litre. This scenario uses a combination of one small oil extrusion plant (Plant 1), seven large oil extrusion plants (Plant 2) and the largest High-Tech biodiesel plant (Plant 5). This solution is highly dependent on buying in soybeans (10193 tons) and contributes relatively little to the objective function value. Not surprisingly, however, at high biodiesel prices no biodiesel is used on-farm for the planting/harvesting activities because the opportunity cost of using biodiesel is relatively high. In fact, biodiesel use on farms is only drawn into the optimum solution at diesel prices exceeding R10.95 per litre, *ceteris paribus*. This is approximately R4.18 per litre higher than the diesel price assumed in the baseline model (i.e., R6.77/litre, which accounts for a R0.94/litre government subsidy).

Evidence from both U.S. and domestic commercial crop farmers suggests that some farm managers prefer planting maize and soybeans in a rotation of equal proportions (i.e., 50% soybeans and 50% maize) (Nieuwoudt, 2010; Whitehead, 2010). If the baseline crop rotation constraint is relaxed to permit a minimum 1/3 soybean – 2/3 maize rotation and a maximum of 1/2 soybean – 1/2 maize rotation, the minimum implicit subsidy for the optimistic scenario decreases by approximately R0.09 per litre. The solution results in the identical quantity of biodiesel production as the baseline model (86184 litres). However, soybeans are no longer purchased in the market as approximately equal areas of irrigated land are planted to soybean (102 ha) and maize (108 ha). Nevertheless, relaxing the baseline rotation constraint does not appear to have considerable influence over the minimum level of government support required to stimulate biodiesel production in the high soybean producing regions of KZN.

When using the less optimistic conversion ratios, as recommended by industry role players and technology suppliers, the situation is somewhat different. As anticipated, the level of government intervention necessary to stimulate on-farm biodiesel production in the soybean producing regions of KZN is markedly higher. Table 5.6 presents a summary of the successive optimisations, again using incrementally higher biodiesel prices, but assuming the less optimistic conversion ratio of 120 litres of oil per ton of soybeans.

Table 5.6: Less Optimistic[*] Baseline Results under Various Farm-Level Biodiesel Prices, assuming Soybean Oil = R8.44/litre and Soybean Oilcake = R3738/ton (2009/10 = 100)

Investment Behaviour						
Biodiesel Price (R/litre)	6.55	8.55	10.55	10.92	12.98	13.34
	(Baseline)					
Oil Extrusion						
Plant 1	No	No	No	Yes (1)	Yes (1)	Yes (1)
Plant 2	No	No	No	No	No	Yes (7)
Sell Soybean Oil (litres)	0	0	0	0	0	0
Sell Soybean Oilcake (tons)	0	0	0	266	514	10796
Biodiesel						
Plant 1 (Low-Tech)	No	No	No	Yes (1)	No	No
Plant 2 (Low-Tech)	No	No	No	No	Yes (1)	No
Plant 3 (High-Tech)	No	No	No	No	No	No
Plant 4 (High-Tech)	No	No	No	No	No	No
Plant 5 (High-Tech)	No	No	No	No	No	Yes (1)
Sell Biodiesel (litres)	0	0	0	44528	86184	1809864
Sell Glycerine (tons)	0	0	0	60	114	2390
Buy Soybean (tons)	0	0	0	0	365	15485
Objective Function Value (R)	497 872	497 872	497 872	498 108	590 464	632 115
Implicit Subsidy (R/litre)	0.00	2.00	4.00	4.37	6.43	6.79

[*] Assumes a yield of 120 litres of soybean oil per ton of soybeans

Under these less optimistic assumptions, the minimum biodiesel price necessary for biodiesel production to be drawn into the optimum solution is approximately R10.92 per litre. This is R0.73 per litre higher than under the optimistic scenario, and implies a government subsidy of R4.37 per litre. Interestingly, however, the optimum solution combines both the smallest oil extrusion (Plant 1) and smallest Low-Tech biodiesel (Plant 1) plants. This is different from the optimistic scenario. Subsequently, the quantity of biodiesel produced at this minimum biodiesel price is significantly lower (41656 litres) under the less optimistic scenario. However, the less optimistic solution does not require soybeans to be purchased to supplement farm production. Importantly, the exclusion of all plants from the optimum solution under baseline assumptions for the less optimistic (arguably realistic) scenario supports the view that individual crop farmers typically do not establish oil extrusion plants or biodiesel plants, owing to the price volatility inherent in the markets for both soybean oil and soybean oilcake (Funke, 2010; Hislop, 2010).

Only at a farm-level biodiesel price of R12.98 per litre does the less optimistic solution combine the largest Low-Tech biodiesel plant (Plant2) with the smallest oil extrusion plant. At this price the identical quantity of biodiesel (86184 litres) is produced as in the optimistic assumptions. However, this solution requires considerably more soybeans to be purchased in the market (365 tons). Moreover, the minimum biodiesel price required to draw in the High-Tech biodiesel plants into the optimum solution under the less optimistic assumptions is R13.34 per litre. This is R2.62 per litre higher than for the optimistic scenario, to achieve the identical level of biodiesel production, using the same combination of plants. This less optimistic scenario, therefore, is even more heavily dependent on buying in soybeans (15485 tons). Biodiesel use on farms is only drawn into the less optimistic solution at diesel prices exceeding R12.94 per litre, *ceteris paribus*. This is approximately R1.99 per litre higher than the minimum diesel price required for on-farm usage of biodiesel in the optimistic scenario.

Relaxing the less optimistic baseline crop rotation constraint to permit a minimum 1/3 soybean – 2/3 maize rotation and a maximum of 1/2 soybean – 1/2 maize rotation, results in the baseline minimum implicit subsidy level required to stimulate biodiesel production in these regions of KZN being unchanged (R4.92/litre). However, the area of irrigated land planted to soybean increases marginally to approximately 73 hectares. Consequently, biodiesel production increases (relative to the baseline) to 45600 litres.

5.3 Effect of Farm Size on Economic Feasibility of Biodiesel Production

Evidence reflecting gains from economies of scale in the biodiesel production process have been mixed (Bender, 1999; Eidman, 2007; Amigun *et al*., 2008a, 2008b). Therefore, an evaluation of the potential influence of farm size on plant choice and level of government intervention necessary to stimulate biodiesel production, whilst holding other baseline variables constant, is interesting. Importantly, these baseline assumptions include equal allotments of arable dryland and irrigated land. Figure 5.1 presents a summary of the minimum level of government support needed to draw biodiesel production into the optimum linear programming solution for the baseline model under both optimistic and less optimistic conversion ratio assumptions at various farm sizes, *ceteris paribus*. Since on-farm soybean production can be supplemented by purchasing soybeans in the market, *a priori* expectations are that farm size will have little effect on the level of government intervention required to encourage domestic biodiesel markets to develop. Importantly, soybeans are purchased at a higher price than which they are sold as an allowance is made for additional cost factors such as transportation and storage (approximately R400/ton).

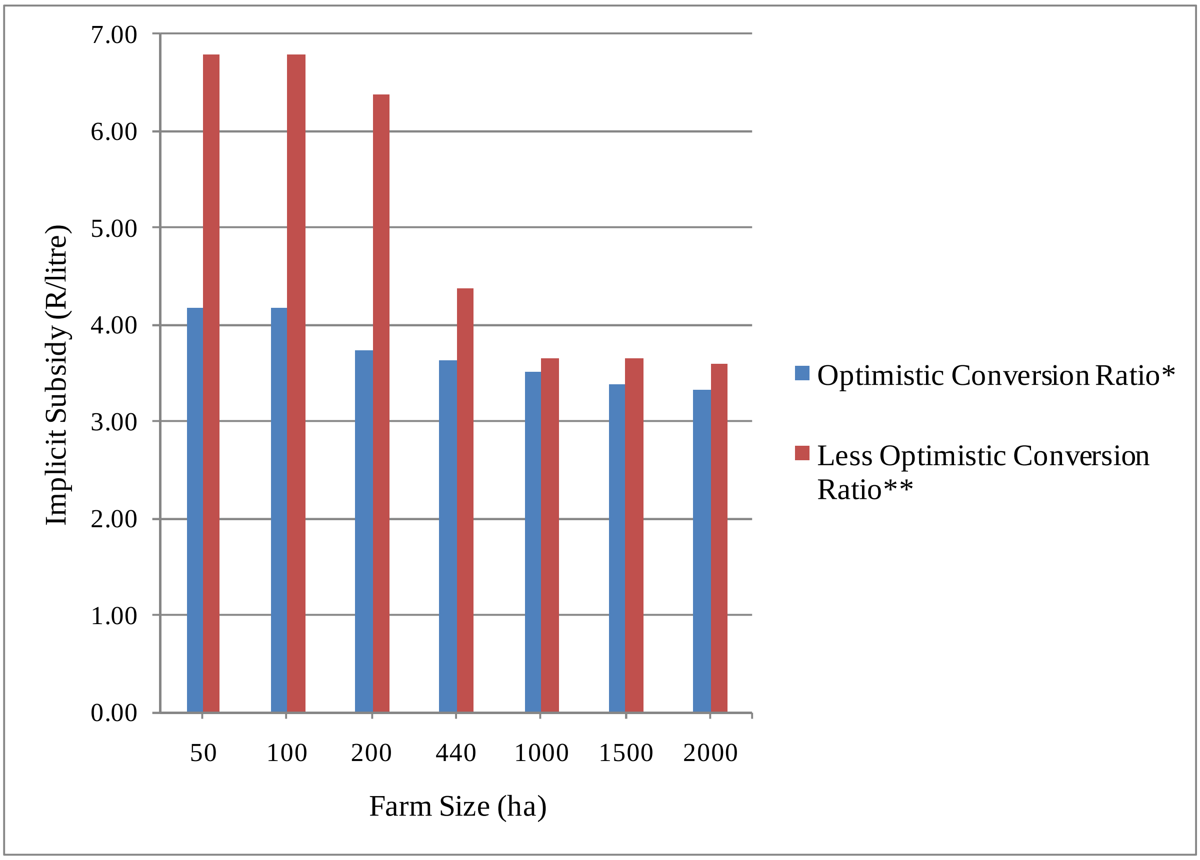

Figure 5.1: Sensitivity of Government Biodiesel Support to Farm Size, *Ceteris Paribus* (Baseline Farm Size = 440 ha) (2009/10 = 100)

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

** Assumes a yield of 120 litres of soybean oil per ton of soybeans

As in the previous section, it is interesting to observe how the combination of oil extrusion plants and respective biodiesel plants change in the various optimisations (see Appendix C). In both optimistic and less optimistic conversion ratio scenarios there is a general trend of increasing capacity and biodiesel production when farm size is increased relative to the baseline scenario. This merely reflects farmers acting in a profit-maximising manner, as the objective function values increase consistently with farm size – irrespective of the level of biodiesel production. Importantly, the minimum level of government intervention necessary to stimulate biodiesel production decreases with increases in farm size under both scenarios. This may indicate that there are some cost saving benefits associated with economies of scale in biodiesel production. However, as established in other observations, these benefits do not appear to be overly significant, particularly at larger farm sizes. As such, the level of government support necessary is not particularly sensitive to farm size (i.e., total soybean production).

Government intervention, therefore, is largest for the relatively small farm sizes (i.e., 50-200 ha) as the total quantity of soybeans produced on these areas is so immaterial that these scenarios rely, almost exclusively, on soybeans purchased in the market (see Appendix C). This is particularly pertinent in the less optimistic conversion ratio scenario. The largest reduction in minimum level of government support for the farm sizes considered occurs between 200 ha and the baseline model (440 ha) for the less optimistic scenario, where the implicit subsidy decreases by R2.00 per litre. In contrast, the largest reduction in the implicit subsidy level for the optimistic scenario occurs between 100 and 200 ha (R0.43/litre).

Importantly, however, the relatively larger farm sizes (i.e., 440-2000 ha) and subsequent higher soybean production levels appear to be considerably less sensitive to the (implicitly subsidised) biodiesel price. This holds true for both scenarios. For example, under the less optimistic conversion ratio assumption the minimum implicit subsidy is approximately R0.78 and R0.07 per litre less at a farm size of 2 000 ha than at the significantly smaller baseline model (440 ha) and 1000 ha farm, respectively. As anticipated, the less optimistic conversion ratio scenario requires consistently more government intervention than the optimistic scenario. The margin between the two scenarios, however, becomes markedly smaller as farm size increases. Nevertheless, it is again apparent that considerable support is needed to stimulate on-farm biodiesel production in the historically high soybean-producing regions of KZN – with implicit subsidies ranging from R3.32 to R4.17 per litre and R3.59 to R6.79 per litre under the optimistic and less optimistic conversion ratios, respectively, for the range of farm sizes considered.

5.4 Effect of By-Product Prices on Economic Feasibility of Biodiesel Production

Weber (1993) and Van Dyne *et al*. (1996) contend that from a small-scale community-based standpoint, biodiesel production opportunities are most suitable for diversified cropping and livestock enterprises, which produce oilseeds and have a need for a dietary protein source for livestock rations. In a similar regard, several authors have suggested that this concept has the greatest potential for success in the event that a large difference between the relative prices that farmers obtain for their oilseed and the price paid for high-protein meal exists (Weber, 1993; Van Dyne *et al*., 1996; Van Dyne & Blase, 1998; Bender, 1999). Therefore, it is useful to examine the effects of higher soybean oilcake prices on the economic feasibility of on-farm biodiesel production in the historically high soybean-producing regions of KZN, holding all other baseline variables constant. Figure 5.2 provides a summary of the minimum level of government support needed to draw biodiesel production into the optimum baseline linear programming solution under both optimistic and less optimistic conversion ratio assumptions at successive soybean oilcake prices, *ceteris paribus*.

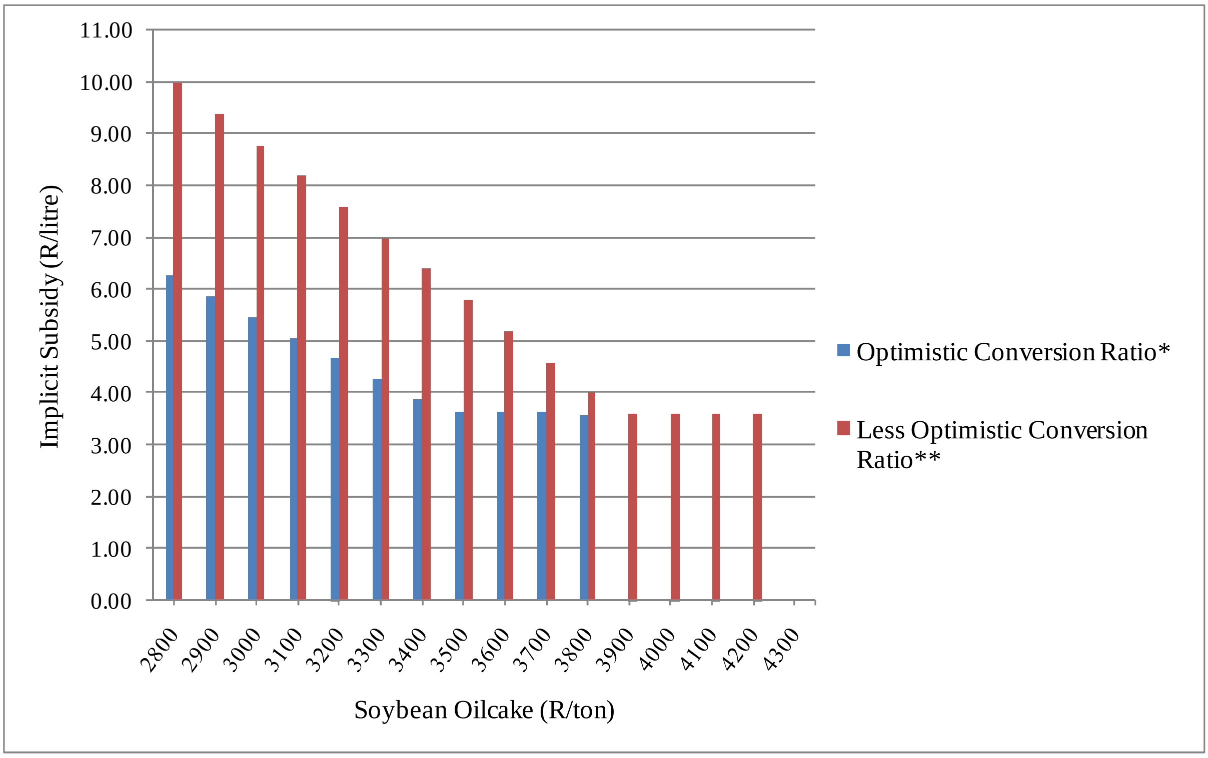

Figure 5.2: Sensitivity of Government Biodiesel Support to Soybean Oilcake Prices, *Ceteris Paribus* (Baseline Soybean Oilcake Price = R3738/ton) (2009/10 = 100)

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

** Assumes a yield of 120 litres of soybean oil per ton of soybeans

Evidently, the value of the soybean oilcake by-product is critically important to the economic feasibility of soybean-based biodiesel production, as there is a relatively strong negative relationship between soybean oilcake prices and the level of government support required to stimulate biodiesel production. Moreover, this holds true for both optimistic and less optimistic conversion scenarios. As in the previous sections, successive optimisations have implications for both the choice of respective plants and biodiesel production levels. However, in both scenarios the optimum plant combinations appear to be particularly robust and do not deviate from the baseline solution, even at relatively high soybean oilcake prices.

It is also interesting to point out that the quantity of biodiesel produced under the less optimistic scenario increases marginally (relative to the baseline) at a soybean oilcake price of R4200 per ton. This solution, therefore, operates the biodiesel plant at full capacity, and requires approximately nine tons of soybeans to be purchased in the market. In contrast, while the plant combinations remain unchanged in the optimistic scenario, biodiesel production decreases to 66793 litres for soybean oilcake prices lower than the baseline level.

In the optimistic conversion ratio scenario, for the soybean oilcake price range between R2800 and R3400 per ton, an incremental increase of R100 per ton results in a reduction in the minimum implicit subsidy necessary to stimulate biodiesel production of approximately R0.40 per litre. A similar situation exists under the less optimistic conversion ratio scenario, where an increase in the soybean oilcake price of R100 per ton results in a decrease in the implicit subsidy level of approximately R0.60 per litre, for the price range between R2800 and R3800 per ton. Outside of the respective price ranges for both conversion ratio scenarios, the contribution of soybean oilcake prices to reductions in the minimum level of government intervention slows considerably. This can be attributed to an increase in the opportunity cost of biodiesel production, as exclusively soybean oil extrusion operations also become more viable at higher soybean oilcake prices (through higher by-product realisation prices). Therefore, this suggests that the baseline minimum levels of government intervention are reasonably robust at relatively high soybean oilcake prices, *ceteris paribus*.

Soybean oilcake prices exceeding R3800 and R4200 per ton result in unbounded solutions for the optimistic and less optimistic conversion ratio scenarios, respectively. This implies that at these prices the linear programming formulation "admits the unrealistic result that an infinite amount of profit can be made" (Schrage, 1984: 16). In the present scenarios, therefore, the inference would be that an infinite quantity of soybeans is purchased in the market and is utilised in an infinite number of plants in the optimum solution.

Since crude glycerine markets are regarded as being both volatile and uncertain, there seems little value in analysing the effects of increased glycerine prices until alternative higher-valued applications for this by-product have been established. Currently, however, this remains an area which requires further research, both domestically and globally. This is compounded by anecdotal evidence suggesting that domestic crude glycerine prices may fall if there is a considerable increase in local biodiesel production.

5.5 Effect of Soybean Oil Prices on Economic Feasibility of Biodiesel Production

The sale of soybean oil in the market essentially serves as an opportunity cost to the production and/or sale of soybean-based biodiesel. The implication, therefore, would be that in the event that soybean oil prices are sufficiently high, farmers would rather sell the soybean oil rather than using it to produce biodiesel (see Table 5.2). As demonstrated in Section 5.2, the viability of on-farm soybean oil extrusion appears to be highly sensitive to the soybean oil price. Therefore, given that SA soybean oil markets are characterised by volatility, it is useful to analyse the effect of changes in the soybean oil price on the minimum level of government support required to stimulate biodiesel production on farms in the high soybean production regions of KZN. Thus, Figure 5.3 presents a summary of the minimum implicit subsidy necessary to draw biodiesel production into the optimum baseline linear programming solution under both optimistic and less optimistic conversion ratio assumptions at successive soybean oil prices, *ceteris paribus*.

The soybean oil price appears to have a relatively limited impact on the economic feasibility of on-farm soybean-based biodiesel in KZN in both conversion ratio scenarios. For example, the implicit subsidy is unchanged at soybean oil prices up to R6.94 and R8.94 per litre for the optimistic and less optimistic scenarios, respectively. Thereafter, the opportunity cost (i.e., increased soybean oil prices) is sufficiently high to warrant successively greater levels of government support to stimulate biodiesel production. Generally, however, under both conversion ratio scenarios a R0.50 per litre increase in the soybean oil price results in a maximum change in the implicit subsidy level of approximately R0.53 per litre, *ceteris paribus*.

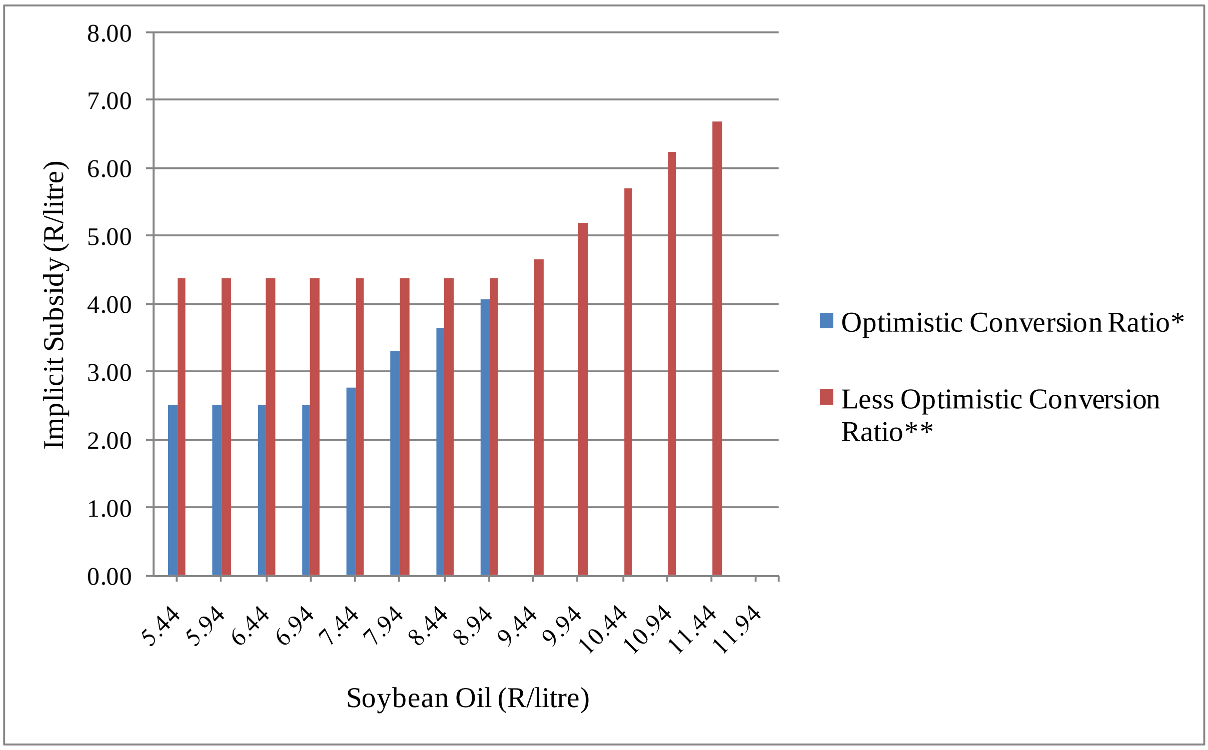

Figure 5.3: Sensitivity of Government Biodiesel Support to Soybean Oil Prices, *Ceteris Paribus* (Baseline Soybean Oil Price = R8.44/litre) (2009/10 = 100)

[*] Assumes a yield of 180 litres of soybean oil per ton of soybeans

[**] Assumes a yield of 120 litres of soybean oil per ton of soybeans

Soybean oil prices exceeding R8.94 and R11.44 per litre result in unbounded solutions for the optimistic and less optimistic conversion ratio scenarios, respectively. Once again, plant combinations appear to be relatively robust to successive optimisations. Only at soybean oil prices exceeding R10.94 per litre does the biodiesel plant capacity increase to the largest Low-Tech biodiesel plant (Plant 2) for the less optimistic scenario. This solution subsequently requires approximately 365 tons of soybeans to be purchased in the market. Similarly, biodiesel production levels in the less optimistic scenario are constant up to this soybean oil price level, and increase only with an enlargement of capacity. Estimated levels of biodiesel production in the optimistic scenario, however, are somewhat different, where soybean oil prices below R8.44 per litre result in biodiesel production reducing (relative to the baseline) to 66793 litres – thereby failing to operate the biodiesel plants at capacity. Nevertheless, it is worth emphasising that the baseline minimum implicit subsidy levels of R3.64 and R4.37 per litre for the optimistic and less optimistic conversion ratio scenarios, respectively, also appear to be robust for a relatively wide range of soybean oil prices.

5.6 Effect of Soybean Prices on Economic Feasibility of Biodiesel Production

Amigun *et al*. (2008a) suggest that feedstock costs are typically the single most important factor influencing the economic feasibility of biodiesel production. With specific reference to soybean-based biodiesel, Tareen *et al*. (2000) estimate that soybean prices account for approximately 75 percent of production costs. Haas *et al*. (2006), however, approximate that this may be as high as 88 percent. Moreover, Coyle (2007) postulates that with recent trends of rising agricultural commodity prices, the cost share of feedstock may continue to increase in the future. Therefore, an analysis of the influence of changes in the soybean price on the minimum level of government support needed to stimulate soybean-based biodiesel production in the soybean producing regions of KZN is well justified.

Figure 5.4 provides a summary of the minimum implicit subsidy necessary to draw biodiesel production into the optimum solution, under both optimistic and less optimistic conversion ratio scenarios, for successive soybean prices. Importantly, the price at which soybeans could be purchased in the market was also varied according to the farm-realisation price. All other baseline variables were held constant. Given that feedstock is such a significant cost component of the biodiesel production process, *a priori* expectations are that relatively lower soybean prices will improve the economic feasibility of on-farm biodiesel production in the high soybean-producing regions of KZN through reduced input costs, and vice versa. Thus, it is anticipated that relatively low soybean prices will result in soybean-based biodiesel being a more favourable means of value-adding for crop farmers in the region.

Under both conversion ratio scenarios, it is clear that there is a relatively strong positive relationship between the soybean price and the level of government support needed to encourage biodiesel production, *ceteris paribus*. Thus, as anticipated, the economic feasibility of biodiesel production improves at lower soybean prices – clearly emphasising the importance of feedstock costs to the production of soybean-based biodiesel. Again, more intervention is consistently required under the less optimistic conversion ratio scenario. Figure 5.4 only considers soybean prices up to R3800 per ton as it is probably unlikely that the soybean oilcake price would be below the soybean price, particularly in the SA case.

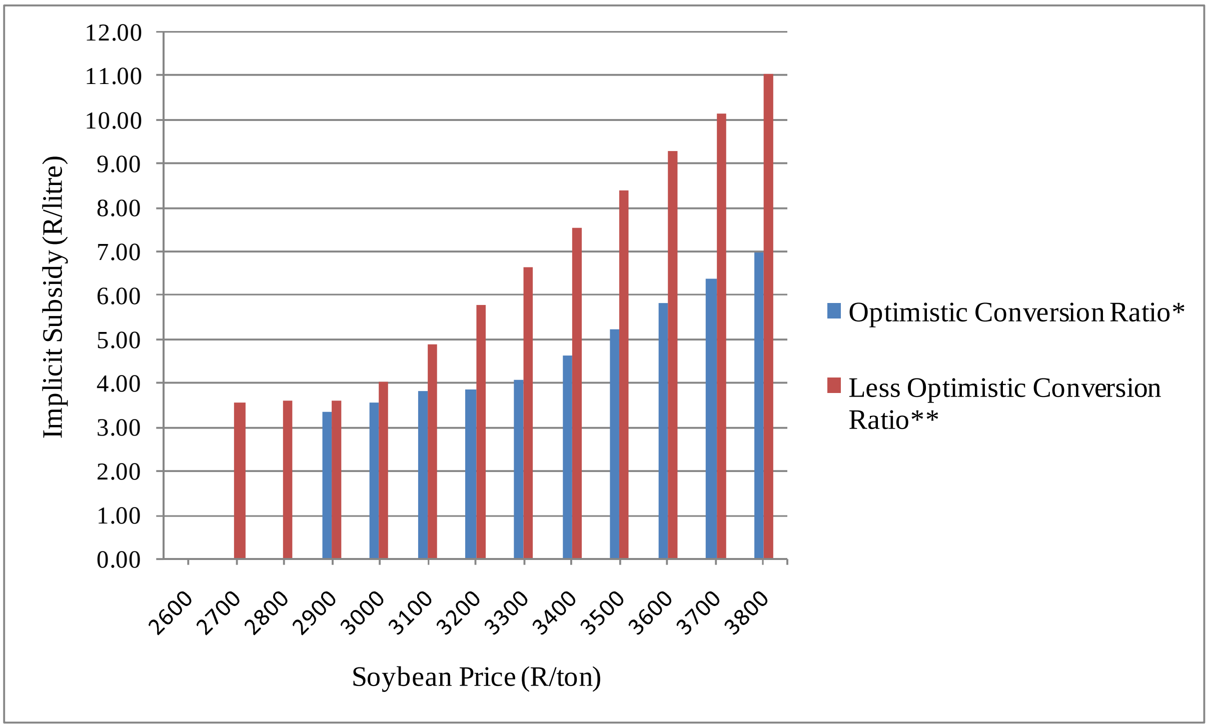

Figure 5.4: Sensitivity of Government Biodiesel Support to Soybean Prices, *Ceteris Paribus* (Baseline Soybean Price = R3039/ton; Baseline Soybean Oilcake Price = R3738/ton) (2009/10 = 100)

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

** Assumes a yield of 120 litres of soybean oil per ton of soybeans

In the optimistic conversion ratio scenario, for soybean producer prices exceeding R3300 per ton, an incremental increase of R100 per ton results in an increase in the minimum implicit subsidy necessary to stimulate biodiesel production of approximately R0.58 per litre. Similarly, under the less optimistic conversion ratio scenario, an increase in the soybean price of R100 per ton results in a rise in the implicit subsidy level of approximately R0.88 per litre, for soybean prices greater than R3000 per ton. However, soybean prices below these respective levels results in the gradual contribution of soybean price adjustments to changes in the minimum level of government intervention to slow considerably. This can likely be attributed to an increase in the opportunity cost of biodiesel production, as exclusively soybean oil extrusion operations also become more viable at lower soybean prices (through reduced input costs), particularly when a large price difference between soybean producer and soybean oilcake prices exists. Accordingly, this suggests that the minimum levels of government intervention are reasonably robust at relatively low soybean prices, *ceteris paribus*. Nevertheless, all else being equal, high soybean prices will likely result in considerable government support being necessary to stimulate soybean-based biodiesel production, since at high soybean prices farmers would rather sell soybeans than use it for biodiesel production (see Table 5.2).

The combinations of plants drawn into the optimum solutions appear to be relatively robust to changes in the soybean price, as increases in biodiesel plant capacities only occur at soybean prices below R3000 and R2800 per ton for the optimistic and less optimistic conversion ratio scenarios, respectively. Biodiesel production levels in the optimistic scenario gradually decrease with an increase in soybean producer prices, and vice versa. In contrast, the predicted biodiesel production quantity remains constant (44528 litres) for the less optimistic scenario, until the plant capacity increases at relatively low soybean prices (e.g., R2700/ton), *ceteris paribus*. Soybean prices below R2900 and R2700 per ton result in unbounded solutions for the optimistic and less optimistic conversion ratio scenarios, respectively. This appears to occur at these price levels because of the relatively large difference between soybean and soybean oilcake prices (i.e., baseline soybean oilcake = R3738/ton), resulting in both oil extrusion and biodiesel production ventures being highly profitable.

5.7 Combined Effects of Soybean, Soybean Oil and Soybean Oilcake Prices on Economic Feasibility of Biodiesel Production

The preceding analyses of the influence of changing an isolated variable in the baseline model are useful in that they enable the researcher to detect which variables are most critical to the economic feasibility of biodiesel production. However, while they may represent an isolated (price) shock to domestic soybean markets, it is worth noting that both world and SA prices for soybean, soybean oilcake and soybean oil are probably likely to move together to a large extent (see Figure 5.5). Since South Africa can be regarded as a relatively small producer of these commodities, domestic prices are influenced by numerous fundamental factors such as crude oil prices; international policies; global weather patterns; international supply and demand levels; subsequent world prices; exchange rates; and domestic production, demand and stock levels (for example, see Geyser & Cutts, 2007). The BFAP model explicitly accounts for these and other factors (Meyer *et al.*, 2008: 331; Funke *et al.*, 2009: 226), and was once again consulted in an attempt to further enhance the sensitivity analysis of this study by simulating scenarios of alternative world prices for soybeans, soybean oilcake and soybean oil and predicting the impact of these on the implicit subsidy required for SA biodiesel production.

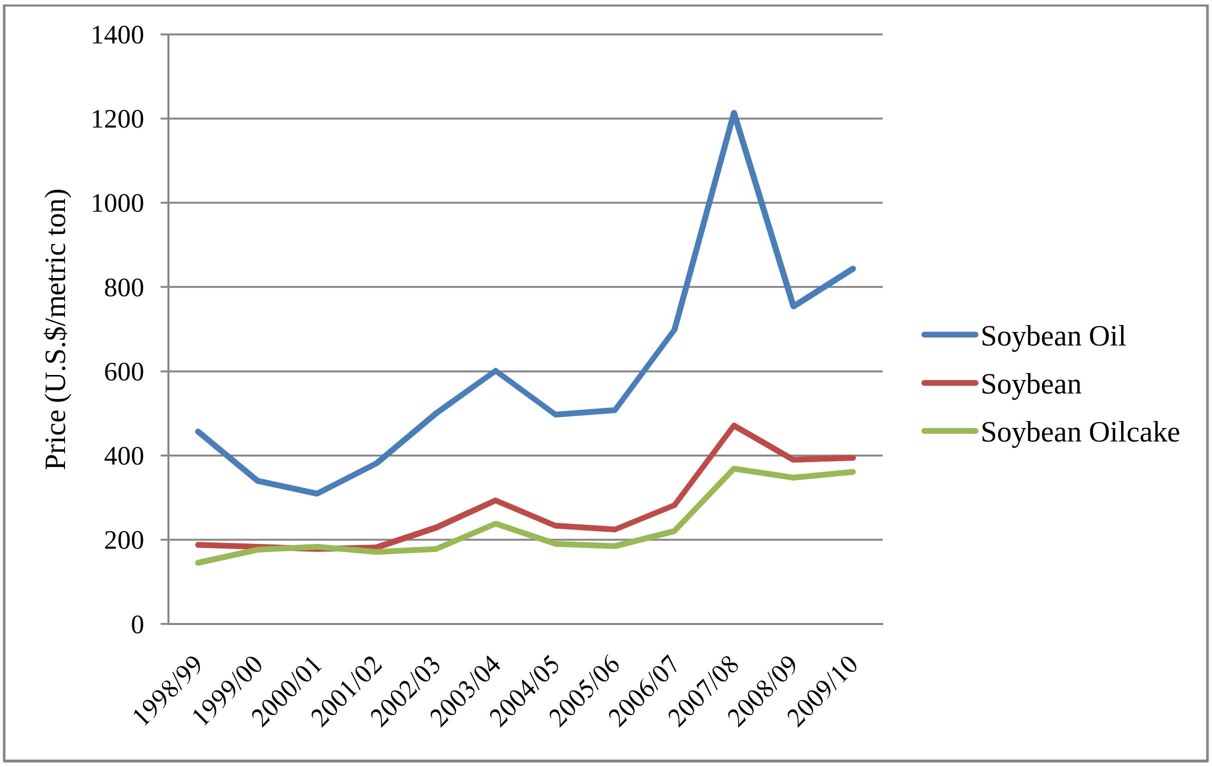

Figure 5.5: World Price Relationships between Soybeans and By-Products, 1998-2010

Source: USDA (2010: 31-33)

Note: Commodity prices reflect the nominal mean prices of U.S., Brazil, Argentina and Rotterdam

Under the 2009/10 price relationships assumed in the BFAP model, simulations suggest that a U.S.$50 per ton price change in the world soybean price infers approximately a R278 per ton change (in the same direction) for SA soybean producer prices[7]. Thus, maintaining the same price ratios between SA soybean prices, soybean oilcake and soybean oil prices that were used in the baseline analysis, five alternative world price scenarios for these commodities are summarised in Table 5.7.

Table 5.7: Summary of Alternative World Soybean Price Scenarios (2009/10 = 100)

Scenario	A	B	C	Baseline	D	E
SA Soybean (R/ton)	2205	2483	2761	3039	3317	3596
SA Soybean Oilcake (R/ton)	2712	3054	3396	3738	4080	4422
SA Soybean Oil (R/ton)	6660	7500	8340	9180	10020	10860

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[7] These are based on the author's calculations on BFAP model solutions received from Funke (2010).

Figure 5.6 presents a summary of the effects these alternative soybean world price scenarios have on the minimum level of intervention required to stimulate soybean-based biodiesel production in the soybean producing regions of KZN, relative to the baseline model. Importantly, the price at which soybeans could be purchased in the market was once again varied according to the farm-realisation prices.

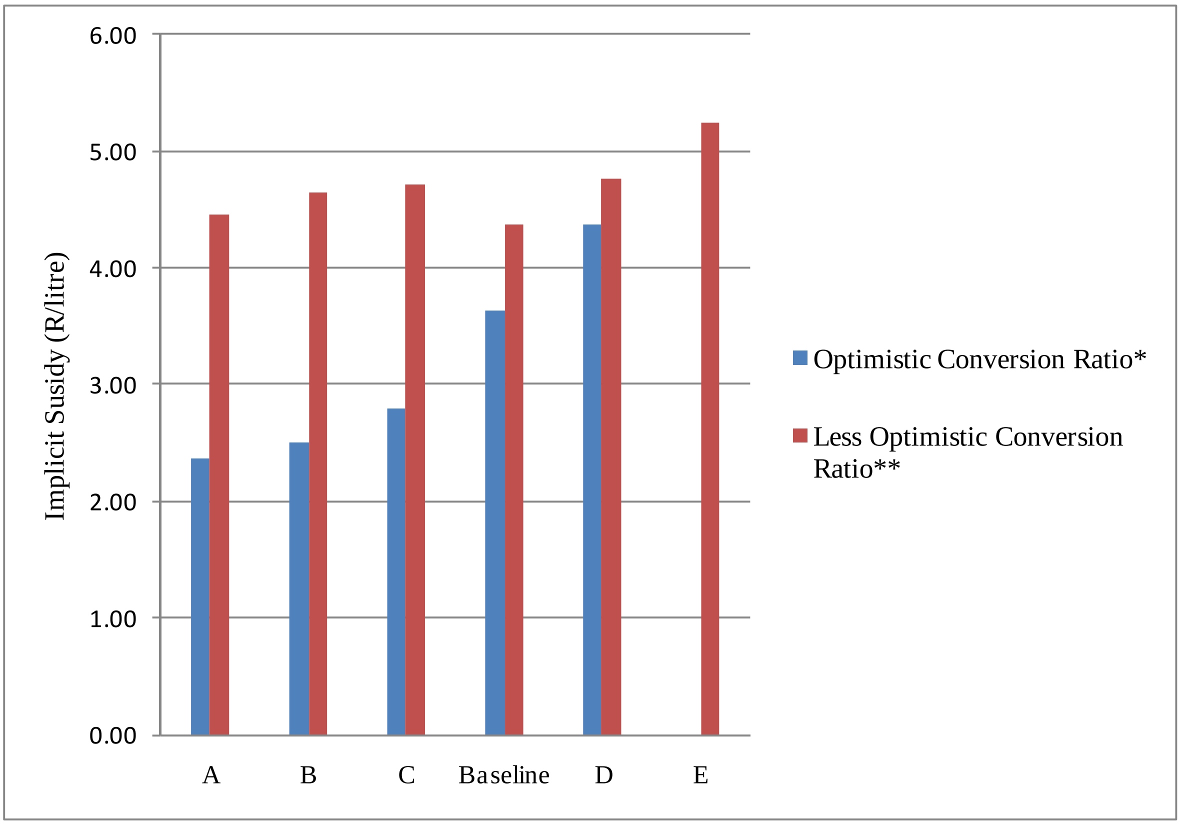

Figure 5.6: Sensitivity of Government Biodiesel Support to Changes in the World Prices of Soybeans, Soybean Oilcake and Soybean Oil, *Ceteris Paribus* (2009/10 = 100)

[*] Assumes a yield of 180 litres of soybean oil per ton of soybeans

[**] Assumes a yield of 120 litres of soybean oil per ton of soybeans

Successively lower soybean world prices result in a steady decline in the minimum implicit subsidy requirements under optimistic conversion assumptions. As in all less optimistic cases, Scenarios A, B and C combine the smallest oil extrusion and biodiesel plants together in the optimum optimistic solutions. Therefore, the ability to reduce production capacity (relative to the baseline) appears to contribute to the steady decline of government support under optimistic conversion ratio assumptions. The same cannot be said for the less optimistic case, however, as these solutions already consistently combine the smallest plants together. Nevertheless, the rate at which lower world soybean prices contribute to lower implicit subsidies in the optimistic scenarios slows owing to dryland sorghum enterprises becoming more attractive at relatively lower SA soybean producer prices. Scenario E results in an unbounded solution for the optimistic situation.

In contrast, the less optimistic implicit subsidy estimated in the baseline model appears to be relatively robust to changes in the world prices of soybeans, as it remains at a broadly comparable level for all scenarios. Interestingly, Scenario C results in a marginal increase in the minimum baseline subsidy (approximately R0.37/litre). This occurs because this solution requires a relatively high biodiesel price subsidy to substitute away from planting dryland sorghum at relatively low world soybean prices. Moreover, the fixed costs of establishing the smallest plant combination also need to be accounted for. The same reasoning can be applied to Scenarios A and B.

5.8 Discussion

The foregoing analyses identified that the economic feasibility of on-farm biodiesel production in the high soybean-producing regions of KZN is highly dependent on the soybean price (i.e., the feedstock input cost) and the soybean oilcake price (i.e., the highest valued by-product). This is consistent with other international studies. For example, Bender (1999) concludes that the economics of biodiesel production can be regarded as being relatively volatile, primarily due to the significant effects of feedstock cost and oilcake meal credits. Importantly, the relationship between these two prices appears to have a significant effect on the viability of these ventures. In contrast, however, farm size and the price of soybean oil do not appear to have considerable influence on the economic feasibility of biodiesel production. The former supports the notion that economies of scale are relatively insignificant in the biodiesel production process.

Since feedstock costs comprise a significant proportion of total biodiesel production costs, numerous authors contend that the future promotion of biodiesel ventures should primarily target a reduction of feedstock costs through the development of new technologies which increase yields of available feedstocks, and/or permit the use of lower cost alternatives (Withers & Noordam, 1996; Zhang *et al*., 2003b; Haas *et al*., 2006; Coyle, 2007; Worldwatch

Institute, 2007; Amigun *et al*., 2008b; You *et al*., 2008). The results of this study broadly support this recommendation. However, the gains from lower input costs appear to be relatively sensitive to the conversion ratios achieved. Furthermore, developing cheaper and more efficient small-scale oil extrusion equipment in particular may also go a long way to improving the viability of these ventures in the SA context.

The results indicate that considerable government intervention is necessary to establish and operate batch process biodiesel plants on commercial crop farms in the historically high soybean-producing areas of KZN. Importantly, these results, under both optimistic and less optimistic conversion ratio scenarios, support the study by Funke *et al*. (2009), who contend that the incentives and commitments proposed by the SA biofuels industrial strategy are insufficient to both establish and sustain a domestic biodiesel industry. Moreover, they are consistent with several international studies which reach the conclusion that government intervention in the form of tax incentives and/or subsidies are necessary for biodiesel to become competitive with conventional diesel (Ahouissoussi & Wetzstein, 1997; Bender, 1999; Fortenberry, 2005; Wassell & Ditmer, 2006; Demirbas, 2007; Martinez-Gonzalez *et al*., 2007; Amigun *et al*., 2008b; Peters & Thielmann, 2008).

Under the baseline assumptions, the less optimistic conversion ratio, as recommended by industry role players and technology suppliers, requires an implicit subsidy of approximately R4.37 per litre to draw biodiesel production into the optimum linear programming solution. Importantly, this is the minimum level of support required in the areas of KZN that are best suited for soybean production, inferring that even more intervention will be needed elsewhere in the province (if soybean-based biodiesel production were pursued). This minimum level of subsidy appears to be relatively robust to alternative scenarios (e.g., farm size, soybean oil price changes, etc.). In addition, the “Low-Tech” small-scale batch processing biodiesel plants consistently appear to be preferable at the individual farm level, unless even greater levels of support are provided, or wide discrepancies between the realisation prices for soybean and soybean oilcake exist.

The SA government must decide whether the benefits from increased biodiesel production (e.g., possible rural development, environmental benefits and favourable international perceptions) outweigh the costs of the considerable government support that is required. For example, obtaining the proposed two percent penetration level of biofuels in the national liquid fuel supply, equivalent to 400 million litres per annum, by 2013 (DME, 2007) using only soybean-based biodiesel produced on farms with batch processors at a minimum (arguably realistic) subsidy of R4.37 per litre, infers that the venture will cost government in the region of R2 billion per annum if they are to meet their target. Importantly, soybeans are believed to have the greatest potential as a first generation biodiesel feedstock (Bender, 1999; Meyer *et al.*, 2008), implying a high likelihood of even more elevated levels of support being required for sunflower- and canola-based biodiesel production ventures.

The primary objectives of the SA biofuels industrial strategy are poverty alleviation and the stimulation of economic activity in the former homelands. Given that South Africa has consistently been a net importer of both soybean oilcake and soybean oil, and the fact that soybean oil is currently a higher-valued product whilst costing less to produce than biodiesel, it is recommended that government consider promoting soybean oil extrusion ventures as a means of stimulating rural development for small-scale farming initiatives rather than soybean-based biodiesel production. Although soybean oilcake and soybean oil markets are characterised by volatility, indications of this research are that considerably less support may be necessary to make these viable business opportunities. However, more research is required to evaluate the economic feasibility of small-scale biodiesel production. This is the focus of the following chapter.

Similarly, commercial farmers are more likely to be incentivised by the soybean oil price than the biodiesel price. Soybean oil extrusion ventures for commercial farmers are likely to be most suited to farmers who are diversified in cropping and livestock enterprises, and, therefore, may have a demand for dietary protein sources such as soybean oilcake. Nevertheless, increased local production of soybean oilcake may result in a positive supply response from domestic livestock industries through more readily available high protein feed inputs. In so doing, the food versus fuel debate against an expansion of biofuel production could essentially be reduced. If, in the future, the biodiesel production process becomes more economical, for example through cheaper and more efficient equipment (both for oil extrusion and biodiesel production) or significantly reduced feedstock costs, government can further evaluate their biofuel policies.

Funke *et al.* (2009: 231) emphasize that the fact that biodiesel is typically more costly to produce than its conventional diesel counterpart "creates a significant challenge for the successful marketing of biodiesel in South Africa, and could hamper the successful development of a biodiesel market, especially in light of voluntary blending as stipulated in the biofuel strategy. It further indicates that the South African industry might face a serious threat if local blending mandates are imposed" – and no tariff protection is provided for domestic producers. Mandates that are used in conjunction with subsidies have proven to be an effective means of promoting biofuel industries around the world. However, the Worldwatch Institute (2007: 314) point out that Germany, now the leading biodiesel producer, first instituted subsidies for biodiesel production which were later followed by mandates.

This may well represent the correct approach to follow in the SA case (should government pursue biodiesel ventures), where subsidies would allow the establishment of domestic biodiesel production systems which utilise feedstock other than waste oils, which arguably have very limited long-term potential and little scope for expanding biodiesel supply. Once SA biodiesel production systems are established, with possible gains arising from the learning curve effects present in biofuel industries, mandatory blends could follow and subsidies could potentially begin to be phased out. This, however, is likely to be a relatively drawn out process, which invariably casts even more doubt as to the SA government's chances of meeting the 2013 targets outlined by the Renewable Energy White Paper.

CHAPTER 6: A NORMATIVE ECONOMIC ANANLYSIS OF COOPERATIVE BIODIESEL PRODUCTION USING SOYBEANS PRODUCED BY SMALLHOLDERS IN KWAZULU-NATAL

The SA biofuels industrial strategy promotes a development-oriented strategy with feedstock produced by smallholders and processed by traditional producer-owned cooperatives. This chapter examines a proposal to apply this strategy to small-scale farmers in KZN, using soybeans as feedstock for biodiesel production. First, it is argued that value-adding cooperatives established under South Africa's current Cooperatives Act would fail to attract the capital and expertise needed to process biodiesel owing to ill-defined voting and benefit rights. Second, a mixed integer linear programming model is used to determine the viability of producing biodiesel from soybeans, viewed from the perspective of the smallholder as grower and co-owner of the processing plant. It is concluded that smallholder participation would require a rental market for cropland, co-ownership of the processing plant in a non-traditional cooperative or investor-owned firm, information and training, and a high level of government subsidy.

6.1 General Overview

The SA government currently encourages the use of cooperatives as organisations that have the potential to promote the development of small-scale farmers and other local communities (Ortmann & King, 2007a, 2007b; Lyne & Collins, 2008). This is not necessarily a novel concept, however, as cooperatives have been endorsed in numerous developing nations as a means to stimulate agricultural growth and rural development (Chibanda *et al.*, 2009; Nganwa *et al.*, 2010), and are a prominent form of business organisation around the world (Cook & Iliopoulos, 2000). Since the primary objectives of the SA biofuels industrial strategy are poverty alleviation and the stimulation of economic activity in the former homelands (Funke *et al.*, 2009), it is not surprising that the biofuels industrial strategy explicitly states that the SA government intends using cooperatives as the preferred organisational vehicle to integrate smallholders into the domestic biofuels industry (DME, 2007).

Most recent SA academic publications have adopted the International Cooperative Alliance's (ICA) definition of a cooperative, which they regard as "an autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly-owned and democratically-controlled enterprise" (ICA, 2010). Ortmann and King (2007a, 2007b) point out that while numerous forms of cooperatives have been established around the world in various business activities, agricultural cooperatives can typically be classified as either marketing, farm supply or service cooperatives.

Lyne and Collins (2008: 180) suggest that agricultural cooperatives can be regarded as vehicles to "facilitate vertical coordination with, or horizontal integration between, small farmers who would otherwise be excluded from value-adding opportunities and discerning markets". With regard to biofuel production, the Worldwatch Institute (2007: 322) postulates that cooperatives may "allow small- and medium-sized producers to share more in the economic gains of the biofuel industry and to negotiate on a more equal footing". Bender (1999) suggests that the processing of biodiesel by farmer cooperatives could potentially play an important role in the development of rural economies whilst using local renewable resources. However, this study argues that the type of cooperatives permitted by South Africa's new Cooperatives Act will not attract the capital or expertise required by smallholders to establish and manage biofuel processing plants. This argument is based largely on theory drawn from the New Institutional Economics (NIE), and in particular the literature relating to ill-defined property rights in traditional cooperatives (e.g., Cook & Iliopoulos, 2000).

A comprehensive history of agricultural cooperatives in general, as well as their development and implementation in SA agriculture in particular, is provided by Ortmann and King (2007a). Similarly, the rationale behind and development of the current Cooperatives Act of South Africa (Act 14 of 2005) has been well documented (Ortmann & King, 2007a; Lyne & Collins, 2008; Chibanda *et al*., 2009; Nganwa *et al*., 2010). An explicit core purpose of this Act was to target and ensure the provision of support programmes for development-orientated cooperatives, established primarily to assist groups previously disadvantaged by the apartheid system (Ortmann & King, 2007a; Lyne & Collins, 2008). Importantly, however, Lyne and Collins (2008: 193) and Nganwa *et al*. (2010: 40) point out that the current Cooperatives Act of South Africa specifies institutional arrangements that are typical of so-called "traditional cooperatives".

Ortmann and King (2007a: 50) contend that "over the past few decades, the rapidly changing economic environment, reflected in increasing globalization and agricultural industrialization, has led many cooperatives to undertake substantial structural changes in order to adapt to the new situation". Lyne and Collins (2008), however, suggest that recent international trends in movements towards new cooperative models can be attributed to attempts to avoid the institutional problems inherent in traditional cooperatives. Subsequently, these authors criticise the current Cooperatives Act of South Africa and warn that "few development-oriented cooperatives are likely to survive the initial stages of enterprise development when weak institutions are imposed on communities bereft of capital and lacking in business skills" (Lyne & Collins, 2008: 182). Thus, Cook (1995) and Ortmann and King (2007a, 2007b) emphasise that both proponents and potential drivers of cooperatives need to be aware of the institutional flaws of traditional cooperatives. These inherent flaws are the focus of the following section.

6.2 Fundamental Institutional Problems Inherent in Traditional Cooperatives

Considerable international research has focussed on the undermining weak institutions of traditional cooperatives and subsequent difficulties they have in raising equity capital (Cook & Iliopoulos, 2000; Ortmann & King, 2007a; Lyne & Collins, 2008). Cook (1995) identified five institutional problems of traditional cooperatives, arising primarily from poorly defined property rights (i.e., voting and benefit rights). He classifies these as the free-rider, horizon, portfolio, control, and influence cost problems. Cook (1995: 1158) suggests further that these ultimately result in "members having tendencies to under-capitalize their cooperatives". The flawed property rights that cause these problems stem from the cooperative principles of Democratic Control, Member Economic Participation and Open Membership and, which legislators have generally interpreted as egalitarian voting rights, patronage-based returns and redeemable/non-tradable equity shares (Lyne & Collins, 2008; Nganwa *et al*., 2010). Causal relationships between these rules of a traditional cooperative, the institutional problems identified by Cook (1995) and their detrimental effects on equity and debt capital have been well documented and are not discussed at exhaustive length here[8].

Cook (1995) suggests that the free-rider problem, occurring particularly in open membership cooperatives, results when property rights are not tradable, insecure, or unassigned. Both internal and external free-rider problems can be associated with traditional cooperatives (Cook & Iliopoulos, 2000; Ortmann & King, 2007a). Thus, Sykuta and Cook (2001: 1275)

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[8] Ortmann and King (2007a) provide a comprehensive review of this literature, while Nganwa et al. (2010) examine these relationships in case studies of development-oriented cooperatives in KwaZulu-Natal.

surmise that the free-rider problems arise "when gains from cooperative action can be accessed by individuals that did not fully invest in developing the gains, whether those individuals are new(er) members or non-members", who acquire identical rights as the initial investors without paying an appreciated market price for their shares (Poulton & Lyne, 2009). Subsequently, Cook (1995) points out that a disincentive for existing members to invest equity capital in their cooperative is created. Nganwa *et al*. (2010: 42) identify an additional internal free-rider problem that is particularly prominent in production/farming cooperatives that unambiguously reward all members equally, a "labour problem", which exists when cooperative members are not remunerated for their individual level of labour input.

Porter and Scully (1987) and Sykuta and Cook (2001) contend that the horizon problem arises in the event that a member's residual claims on the net income generated by an asset do not extend as far as the productive/economic life of that asset. It arises because members of traditional cooperatives are prohibited from transferring and/or trading owner rights/shares at their market values (Cook, 1995; Lyne & Collins, 2008). The implication, therefore, is that investors cannot realise the full benefit of long-term investments as capital gains upon exiting the cooperative (Lyne & Collins, 2008; Poulton & Lyne, 2009). Thus, the horizon problem results in an environment that creates disincentives for members to invest in assets and growth opportunities, particularly those with long-term payoffs (e.g., research and development), in favour of increasing current payments (Cook, 1995; Cook & Iliopoulos, 2000; Ortmann & King, 2007a) and accelerating equity redemptions (Cook & Iliopoulos, 2000).

Sykuta and Cook (2001: 1275) point out that similar to the horizon problem, the portfolio problem stems from "the tied nature of the equity in the cooperative" – where the investment decision is linked to the patronage decision (Cook & Iliopoulos, 2000). The prohibition of transferring and/or trading owner rights/shares at their market values leads to suboptimal investment portfolios, as members cannot reallocate or diversify their own investments in a manner that reflects their individual interests and personal risk preferences (Cook, 1995; Cook & Iliopoulos, 2000; Sykuta & Cook, 2001; Lyne & Collins, 2008; Poulton & Lyne, 2009). Hence, it is not surprising that Cook (1995: 1157) and Cook and Iliopoulos (2000: 336) refer to this as "another equity acquisition problem" facing traditional cooperatives. Lyne and Collins (2008) suggest that the disincentives created by this problem are further exacerbated in the event that risk-averse members use their democratic voting rights to pressurise management into making overly conservative investments.

The control problem is relatively typical of principal-agent problems brought about by a divergence in the interests between the members of the cooperative and its management (Cook, 1995; Nganwa *et al*., 2010). Traditional cooperatives are susceptible to this problem due to the fact that cooperative shares are prohibited from trading at market values (Cook, 1995). Thus, the lack of an equity market, and subsequent market pressures and signals, for cooperative shares renders members incapable of monitoring the cooperative's value and/or evaluating management's performance (Ortmann & King, 2007a; Lyne & Collins, 2008; Poulton & Lyne, 2009; Nganwa *et al*., 2010). In a similar regard, Ortmann and King (2007a) point out that an absence of equity incentive schemes for managers may create further difficulties for traditional cooperatives to align the incentives of mangers with those of shareholders. Arguably what is more important, however, is that shareholders cannot sanction poor managerial performance by disinvesting (Lyne, 2010).

Influence cost problems are present in all organisations where decisions influence the distribution of wealth and/or other benefits among members (Cook, 1995; Sykuta & Cook, 2001), and occur where minority investors with vested interests attempt to manipulate a given decision in pursuit of their own selfish interests (Cook, 1995). Ortmann and King (2007a) note that these costs may include the direct costs of influence activities, as well as the costs of misallocated scarce resources owing to poor decision-making. Sykuta and Cook (2001: 1275) contend further that these costs are more substantial in the event that there are a wide variety of interests among members and/or the potential gains are significant. Nganwa *et al*. (2010) suggest that these problems can likely be attributed to the fact that members of traditional cooperatives have equal voting rights irrespective of their levels of investment. Furthermore, Hendrikse and Veerman (2001) demonstrate that for any given level of equity capital (which is typically scarce in traditional cooperatives), traditional cooperative's creditworthiness is compromised by the influence cost problem, which in turn reduces their ability to raise debt capital. Hendrikse and Veerman (2001) and Poulton and Lyne (2009) contend that this problem is more severe when the degree of asset specificity is high.

In summary, Lyne and Collins (2008: 185) point out that "traditional cooperatives struggle to raise equity capital because ill-defined property rights leave investor-principals without residual claim, without residual control, and without information to evaluate their agent-managers". These authors and Nganwa *et al*. (2010) also highlight the difficulties traditional cooperatives have in raising debt capital, primarily due to the influence cost problem. Chibanda *et al*. (2009: 298) emphasise that "when equity and debt capital are constrained, the cooperative is unable to finance investments in growth assets". This casts serious doubt on South Africa's decision to use traditional cooperatives as a vehicle for small farmers to finance value-adding assets (Lyne & Collins, 2008) such as oil extrusion and/or biodiesel plants. Persistence with this organisational model will most likely limit the role of smallholder marketing cooperatives to one of contracting with a processor. This single contract would replace the numerous small contracts and high transaction costs that the processor would face if he attempted to deal with many individual small growers. Thus, establishment of a traditional cooperative (horizontal integration) could give smallholders access to processors via contractual arrangements (vertical coordination) but only where processors operate. Elsewhere, these cooperatives will have to integrate vertically into processing but this will almost certainly require a shift away from traditional cooperative status in order to attract the capital needed to finance plant and equipment, and the expertise needed to manage it (Lyne, 2010).

6.3 Characteristics of Small-Scale Agriculture in KwaZulu-Natal

Subsistence farming has historically been a feature of poor households in South Africa, including the KZN province, as a means to ensure their livelihoods (Hendriks, 2009a). While the vast majority of rural households derive a relatively small proportion of their total income from agriculture, a significant number are highly dependent on farming activities, as well as attaching a relatively high value to land as a form of social security (Lyne *et al*., 1996). Farmland is seldom privately owned in the former homelands of South Africa, and is administered by tribal authorities who allocate land to household heads and settle boundary disputes. These land allocations confer use rights but households are not permitted to sell land (Lyne & Nieuwoudt, 1991; Kille & Lyne, 1993).

The rural areas of the former KwaZulu homeland (hereafter referred to as Ngonyama Trust land) are characterised by both high population pressure and uniformly small farm sizes (Lyne *et al*., 1996; Crookes & Lyne, 2001). The vast majority of these land allotments are less than two hectares in size (Lyne, 1989; Nieuwoudt, 1990; Lyne *et al*., 1991b; Thompson, 1996; Matungul *et al*., 2001; Dengu & Lyne, 2007; Hendriks *et al*., 2009b). Nevertheless, it is "patently obvious" that the land is not farmed intensively (Thompson & Lyne, 1991: 288). Nieuwoudt (1990) contends that these small farm sizes imply that profits from agriculture, even under optimal technological conditions, are likely to be unattractive when compared to potential wage employment. A similar view is held by Crookes and Lyne (2001).

Given the relatively specific nature of this analysis, it is important to consider some key aspects of crop farming in the Ngonyama Trust lands. Widespread under-utilisation of land in an area where land is scarce and labour is abundant has been explained by the absence of an efficient rental market for cropland (Lyne, 1989; Thompson, 1996). When a household (i) values land for the social security that it provides and (ii) earns more from off-farm wage work than it can from cultivating a very small farm and (iii) cannot lease land to other households that do rely on farming, it will tend to leave cropland idle as there is no opportunity cost attached to under-utilisation. Lyne (1989) estimated that 22 percent of arable Ngonyama Trust land was left idle. Consequently, average crop yields are typically very low (Thompson & Lyne, 1991).

In addition, crops grown by small-scale farmers have a primary purpose of meeting, at least partially, household food security requirements (Matungul *et al*., 2001; Hendriks *et al*., 2009). Staples like maize, dry beans and potatoes feature prominently (Matungul *et al*., 2001; Hendriks *et al*., 2009). However, Whitehead (2010) notes that smallholders in KZN have little or no experience cultivating soybeans – the biodiesel feedstock considered in this analysis. Moreover, Figure 6.1 shows that the vast majority of Ngonyama Trust lands fall outside the regions of high soybean production potential.

Ghatak and Ingersent (1984: 23) regard poverty as “the outstanding characteristic of traditional agriculture”. Numerous empirical studies in the KZN region support this view (for example, see Lyne, 1989; Thompson, 1996; Matungul *et al*., 2001; Hendriks *et al*., 2009b). In fact, in their recent study of the Embo community, Hendriks *et al*. (2009b: 27) conclude that “these rural households have very small farms, produce food largely for subsistence purposes, and have per capita cash incomes less than US$ 2.00 per day – most of which comes directly or indirectly from wage earnings, state pensions and welfare grants”. Lyne (1989: 22) contends that even the relatively wealthy are poor. Therefore, given that limited access to capital is a considerable constraint to rural development in South Africa (Ortmann & King, 2007b), even a large group of smallholders willing to invest in a producer-owned firm would struggle to finance oil extrusion and/or biodiesel plants.

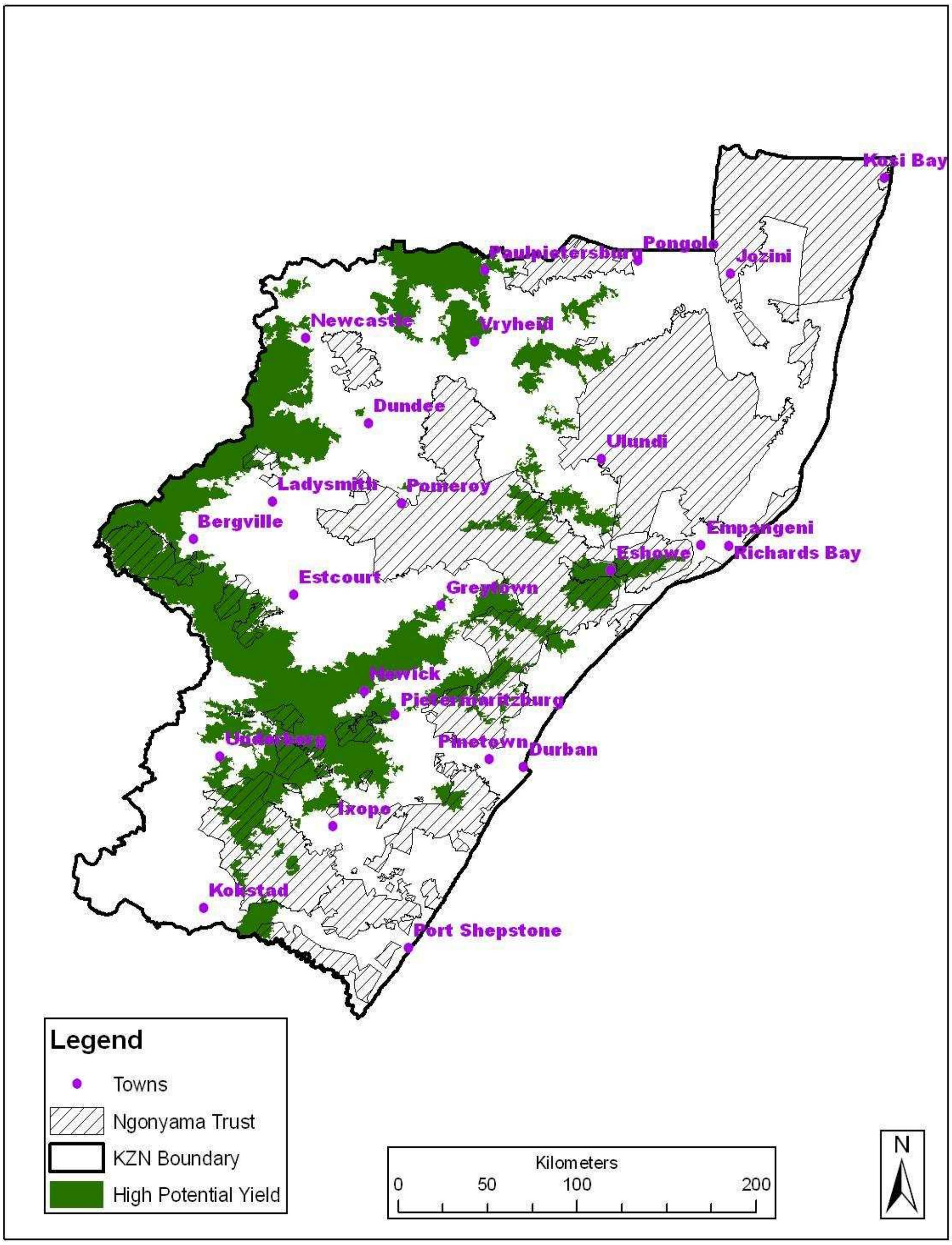

Figure 6.1: Regions of the Ngonyama Trust Lands which Coincide with Areas of Historically High Soybean Production and Significant Cropping Potential for Future Expansion of Soybeans in KwaZulu-Natal

Source: KZNDAEARD (2010).

Lyne (1996) surmises that South African small-scale farmers have limited access to factors of production, credit and information. He points out further that efforts to convert these largely subsistence farmers into commercial growers are often constrained by inadequate property rights and high transaction costs (also see Thompson & Lyne, 1995). The underutilisation of arable land in the rural areas of South Africa has been largely attributed to the general lack of an active rental market, which would create an opportunity cost (in the form of sacrificed rental income) to penalise non-use (Nieuwoudt, 1990; Lyne & Nieuwoudt, 1991; Thompson & Lyne, 1991; Lyne *et al*., 1996). Given that economic theory suggests a positive relationship between exclusive and secure property rights and investments in fixed improvements to land, Kille and Lyne (1993: 108) suggest that there are "causal relationships between property rights to land, land transfers, efficiency of land use, access to credit, and the incentive to conserve and improve land".

6.4 Traditional Cooperatives versus New Cooperative Models

Ortmann and King (2007b) explored the appropriateness of traditional cooperatives for small-scale farmers in two communal areas of KZN (Impendle and Swayimana). In their view, these cooperatives would face considerable free-rider, horizon and portfolio problems during establishment, and that surviving cooperatives would also be constrained by control and influence cost problems. Recent empirical studies in KZN concluded that traditional cooperatives (as specified by the current Cooperatives Act of South Africa) are inappropriate vehicles for promoting rural development owing to poorly defined property rights (Chibanda *et al*., 2009; Nganwa *et al*., 2010).

Thus, Cook and Iliopoulos (2000: 346) point out that "clarifying property rights leads to the increased probability of creating investment incentives". Similarly, Chaddad and Cook (2004) regard secure benefit and voting rights as the most effective means for providing economic agents with necessary incentives to create, maintain and improve assets. Not surprisingly, therefore, in large-farmer settings, institutional changes that better align voting and benefit rights with levels of individual investment have strengthened incentives for patrons and banks to finance cooperative assets. Cases of traditional cooperatives reorganising to alternative ownership structures and amendments being made to cooperative laws to permit "hybrid cooperatives" have been well-documented in recent literature from developed countries (Hendrikse & Veerman, 2001; Chaddad & Cook, 2004; Bekkum &

Bijman, 2006; Woodford, 2008; Lyne & Collins, 2008). These organisational innovations are a response to increasingly competitive and discerning food markets where value must be added to products in order to maintain prices and market share. Value adding requires substantial investment in plant, equipment, branding and promotion that traditional cooperatives could not finance (Lyne, 2010).

Chaddad and Cook (2004) propose a typology in which traditional cooperatives and investment-oriented firms (IOFs) are at two opposing extremes. They identify five alternative, non-traditional cooperative models that vary according to ownership structure (see Figure 6.1), but caution that the legal environment affects the ability of cooperatives to engage in organizational restructuring (Chaddad & Cook, 2004). The upper branch of the figure describes three cooperative models where ownership rights being limited to member-patrons, namely: proportional investment cooperatives (PICs); member-investor cooperatives (MICs); and new generation cooperatives (NGCs). However, all three of these organisational forms explicitly maintain patron control of the cooperative at the cost of limiting access to external sources of capital. Crucially, however, a biodiesel production cooperative is likely to require significant contributions of both capital and expertise to establish and operate. Lyne and Collins (2008: 189) point out that these are "factors of production that the community is sorely lacking but which could be acquired by taking on an experienced business partner".

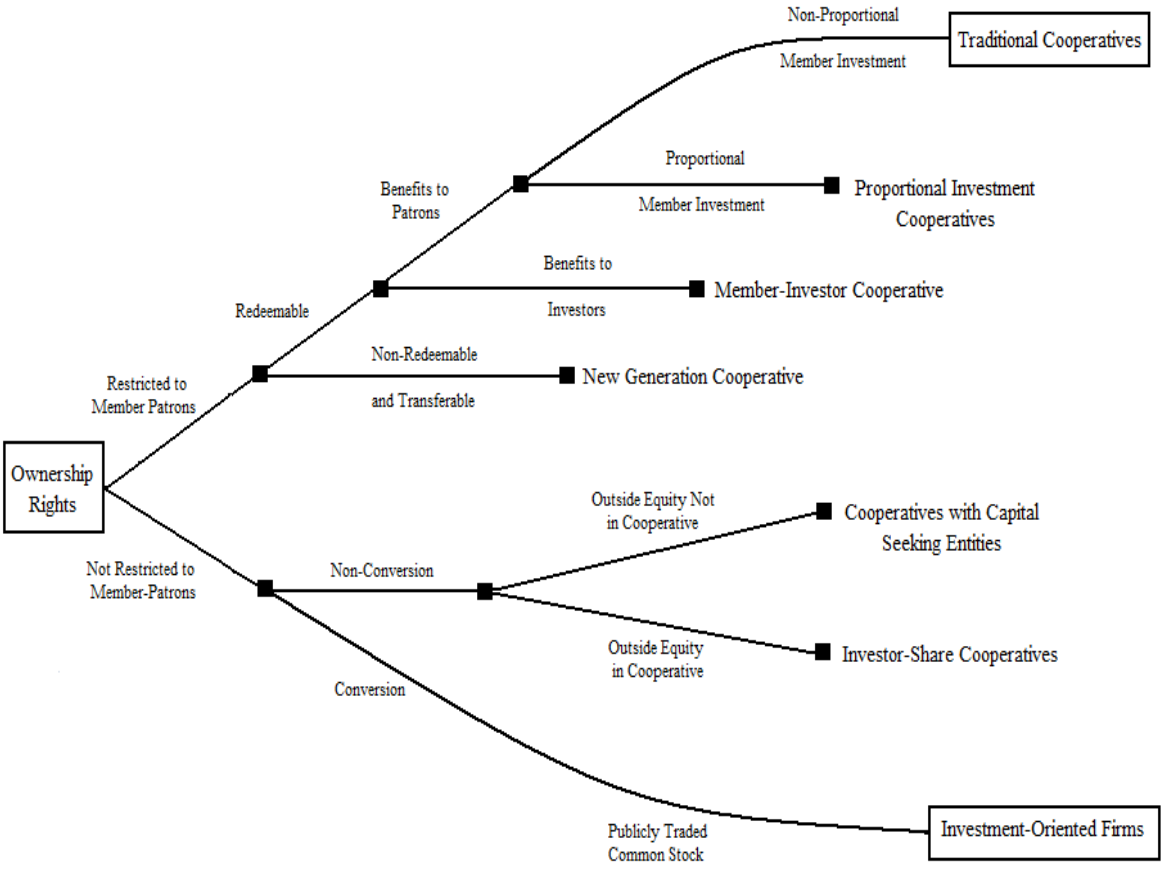

Figure 6.1: An Ownership Rights Perspective of Alternative Cooperative Models

Source: Adapted from Chaddad and Cook (2004:352).

The Worldwatch Institute (2007: 312) suggests that the most efficient means to accelerate an expansion of biofuel production “is for governments to create a policy environment that is conducive to private-sector investment in the development of these fuels”. Moreover, Gordon (2008) contends that if small-scale producers continue to lack the capital, infrastructure or economies of scale to access global biofuel markets, they may be able to participate in biofuel production only as suppliers of raw materials. Therefore, it is important to emphasise that, just like traditional cooperatives, PICs, MICs and NGCs do not permit equity-sharing arrangements with strategic partners as they restrict investment to member-patrons only. Consequently, none of these models is expected to be appropriate for promoting smallholder biodiesel production in KZN. However, NGCs - which are characterised by tradable delivery rights and restricted membership – may well provide an effective means for South Africa’s large commercial farmers to participate in biofuel ventures, as in the U.S. (Jensen *et al.*, 2004; Kenkel & Holcomb, 2009). South Africa’s new Cooperatives Act of 2005 provides sufficient flexibility to convert a traditional cooperative into a NGC.

When considering the potential for KZN’s small-scale farmers to participate in biodiesel production, it would be prudent to explore alternative organisational models that facilitate equity-sharing with strategic partners. Such models are illustrated by the lower branch of Figure 6.1, where ownership rights are not only restricted to member-patrons. However, Chaddad and Cook (2004: 352) point out that with these arrangements “members may have to share profits and eventually control rights with outside investors who are not necessarily patrons of the cooperative and thus may have diverging interests”. The two new cooperative models identified by these authors that permit non-member investment are: cooperatives with capital seeking entities and investor-share cooperatives (ISCs).

The “cooperative with capital seeking entities” model permits participation of an external investor in a subsidiary firm that is co-owned by the cooperative and the external investor (Chaddad & Cook, 2004). However, creating a co-owned subsidiary does not address institutional problems within the cooperative. Accordingly, members will still have little incentive to invest in the cooperative in order to increase or even maintain the cooperative’s shareholding in the subsidiary. The subsidiary, therefore, will ultimately be dominated by the external investor and the conflicts between investors and patrons will persist (Lyne, 2010). With reference to this model, sometimes referred to as the Irish model, Lyne and Collins (2008: 190) suggest that “a unitised trust would better serve as a warehouse for members’ interests in an IOF as tradable units assigning benefit and voting rights that are proportional to individual investments in the trust can be matched directly to shares acquired by the trust in the IOF”.

In contrast to the Irish model, ISCs issue “separate classes of equity shares in addition to the traditional cooperative ownership rights held by member-patrons” (Chaddad & Cook, 2004: 357), although these ownership rights are typically distinct from those of member-patrons. Essentially, multiple classes of shares may be issued to different owner groups, with investors earning market-related returns in dividends and capital gains. While such arrangements can certainly improve a cooperative’s access to capital and expertise, they sacrifice the advantage of inexpensive supply contracts (Sykuta & Cook, 2001) enjoyed by NGCs where investment is proportional to patronage (Bekkum & Bijman, 2006). Chaddad and Cook (2004) and Bekkum and Bijman (2006) provide numerous international examples of ISCs. While they all reward investors with dividends and capital gains through a class of non-redeemable/tradable equity shares, these shares confer zero or limited voting rights to ensure that control remains with patrons. As a result, ISCs still suffer from an influence cost problem (Lyne & Collins, 2008) that is likely to discount the value of its investor-shares relative to an equivalent IOF.

Lyne and Collins (2008: 192) argue that cooperatives could exploit a provision made in South Africa's Cooperatives Act of 2005 for "funds of members" and reorganise, initially, as a MIC. Logically, the MIC could then convert to ISC status by extending membership to non-patron investors. However, the authors recognise that this will depend on how the definition of a patron is interpreted. The Act states that membership is "open to (natural and juristic) persons who can use the services of the cooperative". Thus, it could well be argued that a strategic partner with expertise in processing biofuels is utilising the services of the cooperative and, therefore, qualifies for membership and equity shares. From the specific standpoint of biofuel production, Kenkel and Holcomb (2009) conclude that hybrid cooperative models, which accommodate both patron and non-patron investor owners, will likely be required in order to access sufficient capital to develop and expand biofuel industries in the U.S. These authors, however, warn that the long-term success of these models are largely unproven to date, and specific biofuel production issues involving feedstock pricing (the local monopoly problem), plant location, profit distribution and control may prove problematic in such ISCs.

A proactive response by the SA government to facilitate biodiesel production ventures that are aimed at stimulating economic activity in the former homelands would be to establish and nurture strategic equity-sharing joint ventures between previously disadvantaged smallholders and business partners in the private sector. In this regard, however, Lyne and Collins (2008: 193) conclude that "unfortunately, South Africa's new Cooperatives Act prevents prospective partners from taking up equity in a development-oriented cooperative, and the idea of using a cooperative to warehouse members' shares in an investor-owned firm does not free its members from the problems created by ill-defined property rights. A unitised trust would better serve this purpose". Although the term "patron" is loosely defined in the Cooperatives Act and could be interpreted as including strategic partners, a proactive strategy would amend the Act, making explicit provision for ISCs in order to encourage equity-sharing arrangements between smallholders and strategic partners (Lyne, 2010). Kenkel and Holcomb (2009) report a trend in U.S. ethanol industries where producers have moved progressively away from the NGC model toward those that more closely resemble ISCs.

More specifically, they suggest that “as the industry developed, and investors’ understanding of the grain marketing system improved, project developers shifted toward business models which could access non-producer capital while relying on open market purchases for the grain supply” (Kenkel & Holcomb, 2009: 462).

Another proactive strategy would be to extend public support, currently offered only to cooperatives, to development-oriented IOFs (Lyne & Collins, 2008). Whereas, both the ISC and IOF can alleviate free-rider, horizon, control and portfolio problems, the IOF can also combat the influence cost problem by assigning all voting rights in proportion to investment. In South Africa, however, the IOF alternative may have little political appeal as smallholders could be distanced from control by a majority investor (Lyne, 2010). The Worldwatch Institute (2007: 321) has emphasised that “the more involved farmers are in the production, processing and use of biofuels, the more likely they are to benefit from them”. The following section presents an empirical assessment of the economics of biodiesel production using soybeans grown by smallholders in KZN when it is assumed that there are sufficient smallholders willing and able to grow enough feedstock to supply a co-owned processing ISC or IOF.

6.5 Economic Analysis of Cooperative Smallholder Biodiesel Production

The Department of Minerals and Energy’s (DME) criteria for licenses to manufacture biofuels (DME, 2009: 2) require that “the production of feedstock under irrigation will only be allowed in exceptional circumstances and a detailed motivation will have to be provided”. It further advocates that feedstock must be cultivated and/or sourced from the former homelands, which is consistent with the primary objectives of the SA biofuels industrial strategy of poverty alleviation and the stimulation of economic activity in the previously disadvantaged regions. The mixed integer linear programming model developed in Chapters 4 and 5 used to evaluate the economic feasibility of soybean-based biodiesel production on commercial farms in KZN was modified to represent a KZN smallholder system. Figure 6.1 indicates those areas of the Ngonyama Trust lands that have significant agronomic potential for soybean production and to which this analysis applies.

The smallholder model initially assumed that each farmer operated no more than one hectare of land for grain production. Irrigated land was excluded from the model in view of DME policy requirements. In reality, very few smallholders have access to irrigated land and – if they do - tend to use it for vegetable crops rather than grain crops where they do (Lyne, 2010). As in the large farm model, soybeans were not permitted to exceed the area planted to maize. This constraint provides for necessary crop rotation and a degree of food security on small farms. Smallholders were also assumed to face the same prices, use the same technology, achieve the same yields and display the same level of risk aversion as the foregoing large commercial farmer. On the processing front, it was assumed that smallholders would supply a processing plant that they co-owned as an ISC or IOF, and that (as shown by the large, commercial farm model) a total arable area of 440 hectares would be sufficient to warrant a small processing plant – provided that the solution allocated more than one-third of this land to soybean production.

The smallholder ISC/IOF model was then solved iteratively to find the soybean price at which a co-owned processing plant would become viable. This occurred at a price of R3800 per ton of soybeans, *ceteris paribus*, and the solution for each (1ha) farmer included maize (0.47ha) and drybeans (0.2ha) as its main food crops. Figure 6.3 compares minimum levels of government subsidy needed to draw soybeans (as feedstock for biodiesel) into the linear programming solutions computed for the large commercial farm and smallholder ISC/IOF models. Under the more realistic less optimistic conversion ratio, the minimum level of government intervention needed to produce biodiesel from soybean cultivated by smallholders in the ISC/IOF model is estimated at R12.14 per litre. This is nearly three times as much as the minimum subsidy estimated for the commercial farm model (R4.37/litre). A similar situation exists under the optimistic conversion ratio, where the levels of subsidy are estimated to be R7.22 and R3.64 per litre for the ISC/IOF and large commercial farmer models, respectively.

Higher levels of subsidy required for the smallholder system reflect the exclusion of irrigated land and a greater proportion of the arable area cropped to drybeans for food security purposes. It could, however, be argued that the level of subsidy estimated for smallholders is understated because dryland crop yields observed on small-scale farms in KZN tend to be much lower than those observed on large commercial farms (Lyne, 1989: 9; Whitehead, 2010). More fundamentally, the expected farm gross margin (E) generated by one hectare amounts to just R3159 per annum – despite the government subsidy. It seems unlikely that this level of earnings would be attractive to small farmers as they could earn substantially more by working as unskilled labourers on a large commercial farm. In addition, the costs of developing ISCs or IOFs with large numbers of resource-poor shareholder-patrons (upwards of 400) may be prohibitively high. The largest of the cooperatives studied by Nganwa *et al*. (2010) in KZN had a total of 105 members.

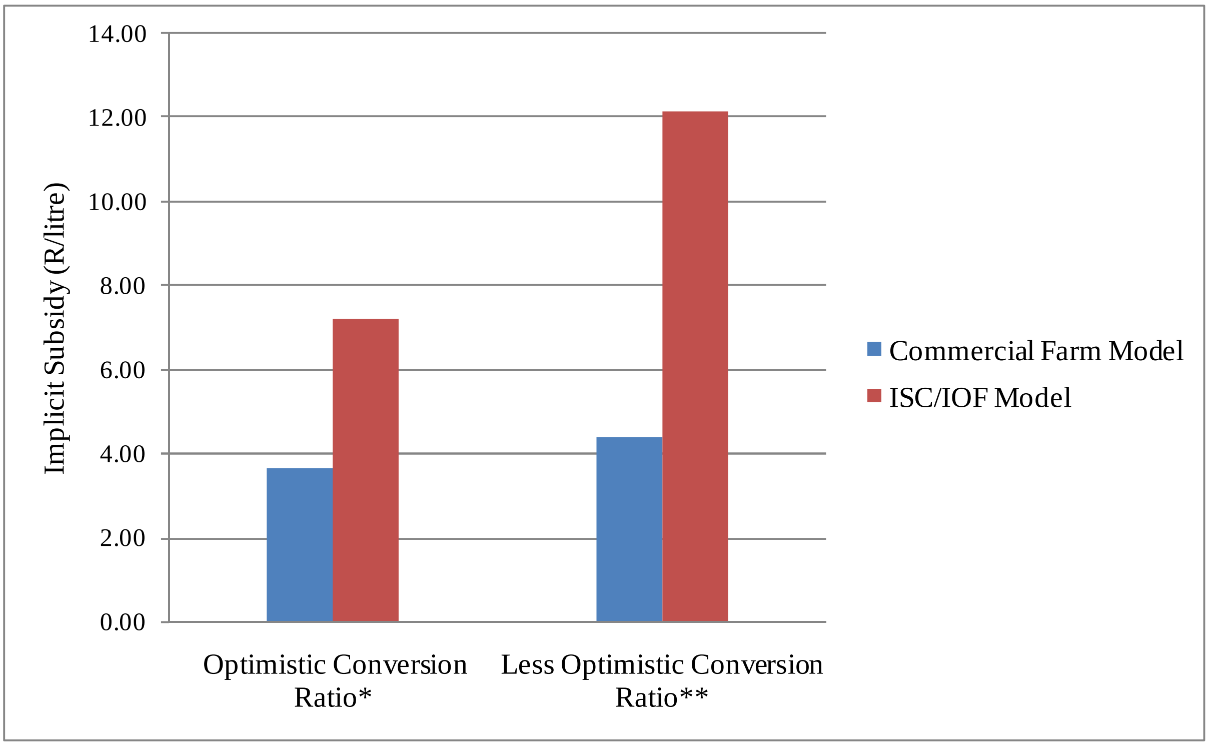

Figure 6.3: Minimum Levels of Subsidy Estimated for Large and Very Small Farmers Growing Soybeans for Biodiesel Production in KwaZulu-Natal (2009/10 = 100)

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

** Assumes a yield of 120 litres of soybean oil per ton of soybeans

It has long been argued that a rental market for Ngonyama Trust lands would encourage voluntary transfers of use rights from non-farming households to emerging farmers, with positive outcomes for equity, income and the adoption of land-saving farm technology (Nieuwoudt, 1990; Kille & Lyne, 1993; Lyne *et al*., 1996). Empirical studies and "action research" conducted in various wards have shown that rental markets for cropland can be activated with only small adaptations to existing tenure arrangements, and that these markets allowed emerging farmers to grow their operations while generating rental income for other households too poor to farm (Thompson, 1996; Crookes & Lyne, 2001). Figure 6.4 compares the earlier smallholder ISC/IOF results with those estimated for a similar ISC/IOF model where emerging farmers have hired idle land from neighbours and increased their arable areas operated from one to 10 hectares.

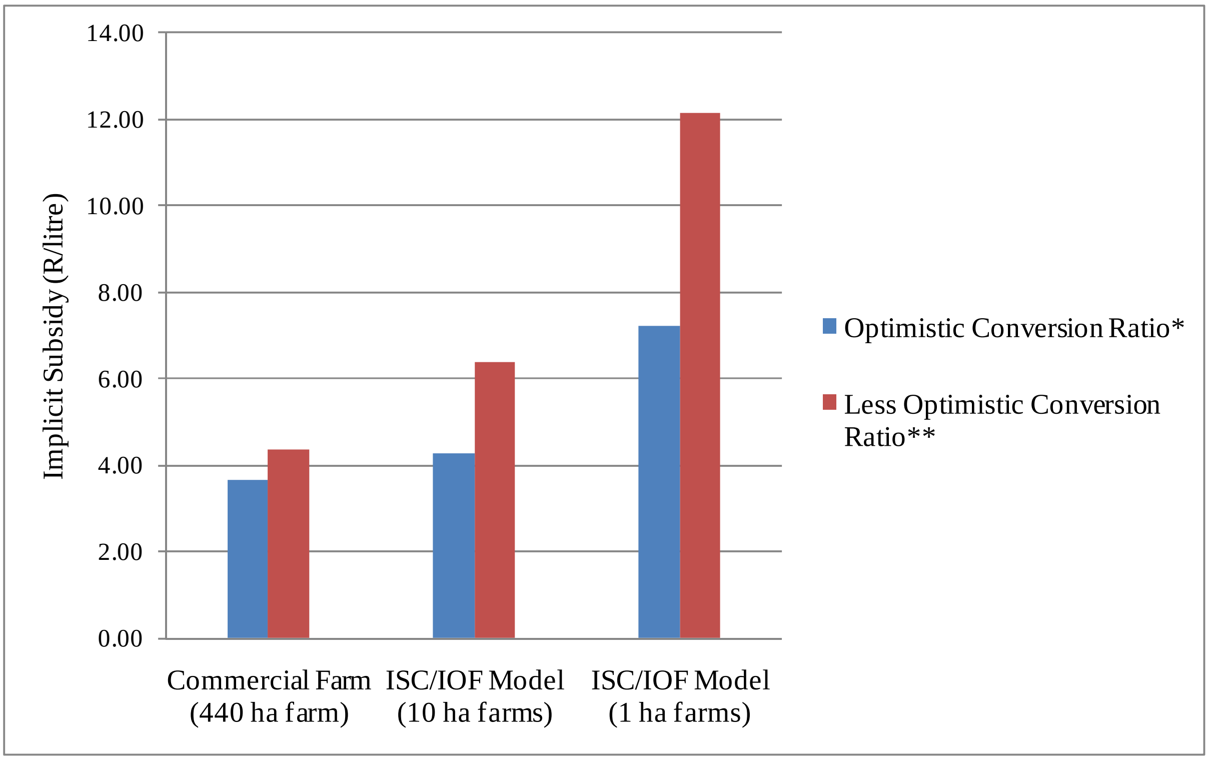

Figure 6.4: Minimum Levels of Subsidy Estimated for Large, Emerging and Very Small Farmers Growing Soybeans for Biodiesel Production in KwaZulu-Natal (2009/10 = 100)

* Assumes a yield of 180 litres of soybean oil per ton of soybeans

** Assumes a yield of 120 litres of soybean oil per ton of soybeans

In this case, expected annual farm gross margin (E) increases from R3159 to a meaningful R29838 per annum, and the number of shareholder-patrons declines to a much more manageable number (44). The required level of subsidy is estimated to fall almost to the level required for the large commercial farmer, the remaining difference reflecting mainly the absence of irrigation land.

6.6 Discussion

While the SA government has undoubtedly recognised the need and importance of promoting rural development in the former homelands, the current Cooperatives Act of South Africa stipulates conditions which are typical of traditional cooperatives. Consequently, they are likely to suffer from a myriad of institutional problems associated with inadequately defined property rights. Moreover, contrary to the international trend of amending cooperative legislation in order to permit and encourage investment by patron and non-patron members, the SA Cooperatives Act has essentially denied development-orientated cooperatives access to the complementary capital and expertise that strategic equity partners could provide. Access to external sources of financial and human capital is expected to play an important role in the successful and sustainable development of biofuel industries, both globally and in South Africa.

This issue is particularly pertinent if smallholders are to engage in the biofuel industry as more than just feedstock producers, which - it could be argued - should be the policy objective if government is serious about maximising the benefits for poor rural communities. The SA government should not underestimate the importance of appropriate business models in achieving this objective and this research supports recent calls for the current Cooperatives Act to be amended to give cooperatives a higher degree of flexibility in their choice of institutional arrangements. It follows that the industrial biofuel strategy proposed for South Africa should be amended to recognise smallholder ISC or IOF biodiesel processing models, and that government support dedicated to traditional smallholder cooperatives should also be used to establish and nurture these alternative forms of business organisation. In addition, more general problems constraining economic development in the Ngonyama Trust lands need to be addressed if cooperatives (or other forms of business organisation) are to play an important role in pro-poor development initiatives. These problems include uncertain property rights and poor physical infrastructure that limit access to information and markets, including land rental markets.

With specific regard to the production of soybeans in KZN as feedstock for biodiesel, the results of this chapter show that local processing would require on-going subsidies - regardless of whether the soybeans are grown on large or small farms, or whether irrigated land is used or not. Pro-poor rural development might be better served by promoting smallholder soybean oil extrusion ventures that are expected to require less subsidy and which maintain the advantage (as for biodiesel production) of producing oilcake that can be used as a high protein input in animal feeds. South Africa has consistently been a net importer of both soybean oil and oilcake. The results also suggest that smallholder participation is unlikely in the absence of a rental market for cropland as prevailing farm sizes are too small to make commercial production of soybeans a worthwhile proposition – even with high levels of subsidy. Preconditions therefore include a rental market for cropland, support for smallholder organisations like ISCs or IOFs that encourage investment by patrons and strategic equity partners in processing plant, and extension and training for small farmers who typically have little experience in the production of soybeans.

CONCLUSION AND POLICY RECOMMENDATIONS

Historically, alternative energy technologies have been dependent on sustained governmental support in order to be competitive with fossil fuels in the marketplace. Biofuels are no exception, and a significant portion of recent increases in global biofuel production can be attributed to government support in these industries – particularly among the current leading biofuel producers (such as the U.S., the E.U. and Brazil). Therefore, government intervention in biofuel markets, at least in the developmental stages, appears to be essential. The results of this study support the initial hypothesis that on-farm biodiesel production in KZN, at both the commercial and small-scale level, is currently not an economically viable alternative to fossil fuels, and indicate that considerable government support (subsidy) is necessary to establish and operate batch process biodiesel plants on both commercial and smallholder crop farms in the soybean-producing areas of KwaZulu-Natal (KZN).

Importantly, significantly more support will be required at the small-scale farm level. Therefore, this study suggests that the incentives and commitments proposed by the South African (SA) biofuels industrial strategy are insufficient to both establish and sustain a domestic biodiesel industry. Moreover, these results are applicable to the areas of KZN that are best suited for soybean production, inferring that even more intervention will be needed elsewhere in the province if soybean-based biodiesel production were pursued. Soybeans are also believed to have the greatest potential as a first generation biodiesel feedstock, implying a high likelihood of even more elevated levels of support being required for sunflower- and canola-based biodiesel production ventures.

Results of this study identified that the economic feasibility of on-farm biodiesel production in the soybean-producing regions of KZN is highly dependent on the soybean price (i.e., the feedstock input cost) and the soybean oilcake price (i.e., the highest valued by-product). The relationship between these two prices appears to have a significant effect on the viability of these enterprises. Therefore, since feedstock costs comprise a significant proportion of total biodiesel production costs and are often regarded as the single most important factor influencing the economic feasibility of biodiesel production, future promotion of biodiesel initiatives should primarily target a reduction of feedstock costs through the development of new technologies which increase the yields of available feedstocks and/or permit the use of lower cost alternatives. Prominent technological innovations of this nature may include second and/or third generation biofuels, as well as biotechnology. Central to both these arguments, however, is the importance of addressing constraints to technology adoption and market participation. It is also advisable, therefore, that the availability of feedstock dominates the site selection decision. In contrast, glycerine markets are currently regarded as being volatile and uncertain. It is recommended that alternative applications for this by-product be explored in future research if it is to make a significant contribution to the economic viability of these ventures.

With the likely presence of experience curve effects in biodiesel industries (i.e., the reduction of average unit costs as a function of time and/or cumulative output in the industry), it is recommended that should the SA government wish to pursue biodiesel production – which is believed to be a genuine policy decision – it is imperative that they hasten their attempts to finalise and implement a comprehensive, long-term, biofuel policy framework. Furthermore, since the vast majority of economic feasibility studies, irrespective of the scale of production, establish the need for governmental support in biofuel industries, it is suggested that the proposed SA biofuels industrial strategy, which advocates that only previously disadvantaged individuals producing biofuels in the former homelands will be eligible for government support, may need to be revised if South Africa is to have a realistic chance of achieving its proposed biofuel targets. There are also concerns surrounding the fact that South Africa’s commitment to the framework of the Renewable Energy White Paper is not binding. Less ambiguous biofuel policies would certainly go a long way to creating a more conducive environment for stimulating private investment in domestic biofuel initiatives.

If the SA government continues to view and promote biofuel enterprises as a means of rural and economic development in the former homelands, this research advocates that traditional cooperatives should not be the mechanism to do so. It is vital that government does not underestimate the crucial importance of appropriate business models in achieving their rural development objectives. Thus, this research supports recent calls for the current Cooperatives Act to be amended to give cooperatives a higher degree of flexibility in their choice of institutional arrangements. Accordingly, this would also infer a need to revise the proposed SA industrial biofuel strategy so that it recognises smallholder investor-share cooperative (ISC) or investment-oriented firm (IOF) biodiesel processing models, and that government support dedicated to traditional smallholder cooperatives should also be used to establish and nurture these alternative forms of business organisation. However, it is also critical that government address more fundamental problems that constrain the economic development of the former homeland areas if cooperatives (or other forms of business organisation) are to play an important role in domestic development-oriented biodiesel initiatives. These problems include uncertain property rights and poor physical infrastructure that limit access to information and markets, including land rental markets.

Given that South Africa has consistently been a net importer of both soybean oilcake and soybean oil, and the fact that soybean oil is currently a higher valued product whilst costing less to produce than biodiesel, it is recommended that government rather consider promoting exclusively soybean oil extrusion business ventures as a means of value-adding for smallholders, rather than soybean-based biodiesel production. Although soybean oilcake and soybean oil markets are characterised by volatility, indications of this research are that considerably less public support may be necessary to make these business opportunities viable - even at the relatively small-scale level.

However, the results also indicate that smallholder participation may well be unrealistic in the absence of a rental market for cropland as prevailing farm sizes are too small to make commercial production of soybeans a worthwhile proposition. Specific requirements for smallholder involvement, therefore, include (i) the establishment of a rental market for cropland; (ii) support for smallholder organisations like ISCs or IOFs that encourage investment by patrons and strategic equity partners in processing plants; and (iii) considerable extension and training for smallholders who typically have very limited experience cultivating soybeans. Nevertheless, increased local production of soybean oilcake may result in a positive supply response from domestic livestock industries through more readily available high protein feed inputs. In so doing, the food versus fuel debate against an expansion of biofuel production could be reduced. Developing cheaper and more efficient small-scale oil extrusion equipment in particular may contribute significantly to improving the viability of biodiesel enterprises in the SA context.

Future research could also be geared towards determining whether biodiesel subsidies (or other forms of public support) are economically justifiable at the national level in South Africa (i.e., examine if the national benefits outweigh the costs of these enterprises). Should government wish to pursue development-oriented collective smallholder biodiesel initiatives, it may be advisable that more comprehensive small-scale models are developed to aid this decision. Importantly, these should incorporate more appropriate crop yields, food security requirements and management practices, as well as the additional costs of extension services and transaction costs of collective action. Comparable feasibility studies for large-scale continuous flow biodiesel plants, as well as alternative and/or future generation biofuel feedstocks could also assist policymakers in making informed decisions.

Finally, bioethanol and biodiesel are currently the leading biofuel varieties produced worldwide. The main contributions of these biofuels will likely be to support farmers and augment the existing supply of fuels used in transportation sectors. Under current production levels biofuels contribution to global energy demand is modest. Their contribution in the SA context, however, is currently insignificant and may remain this way without clear government policies on renewable energy and prolonged government support for such industries. Despite the fact that global biofuel production levels are expected to continue to increase in the future, with a similar trend potentially existing in South Africa, biofuels are unlikely to be a panacea and should be used in conjunction with other renewable energy technologies. Nevertheless, continued technological advancements, infrastructure development, and unambiguous government policies and interventions (through the provision of appropriate incentives) will certainly be central to the future developments of biofuel industries.

SUMMARY

Global biofuel production has risen substantially in recent years, driven primarily by government support in these industries. The stated motivations for biofuel initiatives are numerous and have varied over time. Among the most prominent of these are to address concerns over energy security, goals to improve environmental quality, decreased traffic congestion, reductions in the tax costs of farm subsidy programmes, improving farm incomes and enhancing rural economic development. Although biodiesel production has been increasing at a proportionally higher rate than bioethanol in recent years, the latter clearly dominates biofuel production worldwide. The leading producers of biofuels include the U.S., Brazil, and the E.U., with the vast majority of global production originating from these regions. Whilst numerous Asian and Latin American countries are becoming increasingly important biofuel producers, Africa's current contribution to global biofuel production levels can be regarded as being comparatively insignificant. However, with a relative abundance of underutilised land and labour, as well as favourable growing conditions, various African countries have been identified as having significant biofuel production potential.

The feedstocks necessary to produce biofuels will largely originate from the agricultural and forestry sectors. However, the large expected increase in biofuel production has raised numerous questions with regards to the feasibility, approach, and potential impacts of such activities - particularly the potential social and environmental implications. Thus, whilst undeniably important, the decision to expand biofuel production should not be based upon economic concerns alone, as there are a number of other issues including potential land use changes, conflicts with food production, deforestation, loss of biodiversity, and effects on both water quality and quantity that also need to be evaluated. It is these issues and debates that have contributed significantly to biofuels being such a topical subject matter.

The fact that agricultural commodities have become inputs for energy production has caused agricultural and energy markets to converge, with major commodity prices showing an increased correlation with crude oil prices in recent years. This has caused a trade-off between food and biofuel production. Accordingly, there have been considerable debates over the potential adverse implications of diverting food crops for the production of biofuels, and subsequent rises in commodity prices, will have on global food, feed and fibre markets, as well as food security. Since biofuels have only recently had a relatively significant introduction into fuel markets, the full extent of potential impacts on these markets are still

largely uncertain. Distributional considerations, however, suggest that Sub-Saharan Africa and Latin America will be the most vulnerable regions to price increases for various food commodities, reductions in the availability of calories, and subsequent increased levels of malnourishment.

Nevertheless, it has been established that the demand for biofuels is only partly responsible for recent increases in food prices. They have also been attributed to short-term trends such as low inventory levels, supply shocks, monetary policy, and speculation. It has been suggested that enhanced agricultural productivity will serve to reduce the upward pressure that biofuels impose on food prices, and may simultaneously improve food security. Prominent technological innovations of this nature include second and/or third generation biofuels, as well as biotechnology. Central to both these arguments, however, is the importance of addressing constraints to technology adoption and market participation by developing countries.

In addition to the food versus fuel debate, other prominent discussion points have revolved around concerns surrounding the carbon and net energy balances of biofuels, and apprehensions about the degree of sustainability of biofuel feedstock production. The results of studies on the carbon and net energy balances of biofuels have been mixed, and are highly dependent on their underlying assumptions. However, there appears to be consensus that the net energy balances for soybean-based biodiesel and sugarcane-based bioethanol are more favourable than that of maize-based bioethanol. Land and water resources are already limiting factors in the production of agricultural commodities in many countries. Therefore, a continued global expansion of biofuel production, and subsequent price increases for numerous agricultural commodities, may have significant implications for land use, with potentially adverse environmental consequences through increased cropping intensity and/or an expansion of cropping area. The extent of such effects will depend critically on agricultural management practices and which biofuel crops see the most significant expansion. These factors will typically vary by region.

While future generation biofuel technologies promise to have superior yields and be more environmentally friendly than their predecessors, they are also expected to be suitable for marginal lands that are not productive in traditional agricultural practices. Moreover, they will make use of a wider range of biomass resources that do not compete directly for food. It would, however, be naive to assume that optimistic renewable fuel targets that have been set by various countries can be met by only drawing marginal lands into production, and therefore, some land use changes will inevitably occur. Thus, against a backdrop of considerable debate and controversy surrounding the environmental footprint of biofuels, particularly regarding deforestation and the competition of biofuels with food and feed, it has been suggested that establishing sustainability standards and certification schemes are a possible means to ensure that biofuels are produced in a sustainable manner. Another consideration, however, should be that continued advancements in biotechnology may further improve the productivity of current crop varieties, arguably reducing the land intensity of biofuels, as well as develop new, superior biofuel feedstocks in the future.

Alternative energy technologies have historically been highly dependent on sustained governmental support/incentives in order to be competitive with traditional fossil fuels. Importantly, this includes biofuels. While a significant driver of the recent increases in biofuel production has been the rising real oil price, prolonged government intervention has undoubtedly been an essential feature of the development of the biofuel industries in many of the present global market leaders in biofuel production. Furthermore, trends indicate that this will continue in the future. Biofuel development can be influenced by numerous national policies, in multiple sectors, at various stages in the supply chain – ultimately creating favourable market conditions for the production of biofuels. While a wide variety of policy tools are available for government intervention in biofuel markets, the cost effectiveness as well as the distributional implications of each will vary, creating both winners and losers among economic agents. This study evaluated the important characteristics of some widely used biofuel and related policies, of which excise tax credits, renewable fuel standards, and mandatory blends are universal.

In general, the majority of agricultural and trade policies provide net benefits for agricultural producers, while explicit energy policies strive to address the problems that result from oil consumption. Most explicit biofuel policies result in a reduction in the consumption of crude oil at the national level, owing to either increased production of biofuel or a reduced demand for oil. Furthermore, policies that stimulate the production of biofuels typically raise farm income. The majority of policies’ abilities to reduce greenhouse gas emissions are largely uncertain, while their respective implications for consumer welfare and government revenue are mixed, and typically vary by policy. No individual policy, however, will provide an optimum solution under all circumstances. Continued research into dynamic policies that, for example, vary according to crude oil prices and account for both energy security and environmental impacts of biofuels could be very useful in years to come.

Energy is vital to all aspects of development. Subsequently, both conventional petrol and diesel fuels have significant importance in the economies of developing countries. Currently, petrol is the most prominent fuel-type in South Africa. However, the agricultural sector is clearly dominated by the consumption of diesel. Biodiesel is regarded as being a renewable diesel-fuel substitute that can be used in blends or pure form in compression-ignition engines. Biodiesel has the advantages of diminishing dependence on foreign petroleum, mitigating greenhouse gas emissions, and generally improving urban air pollution. Internationally, biodiesel is a relatively well-established fuel, with campaigns being planned and implemented in numerous countries to introduce and encourage the use of biodiesel. Under current production patterns the leading biodiesel producing nations by volume include Germany, U.S., France, Argentina and Brazil. In comparison, biodiesel industries on the African continent are currently regarded as being in their developmental stages.

The choices of biodiesel production process and feedstock variety are important economic considerations, since they have considerable implications for both capital and operating costs. However, alkali-catalysed transesterfication appears to be the most frequently utilised process for biodiesel production, particularly at the commercial level. While biodiesel can be made from numerous feedstocks, it is currently mainly produced from vegetable oils. The relative importance and cost share of biodiesel factors of production may vary by region. However, there appears to be consensus among researchers that raw materials (feedstock) are typically the most significant cost element of biodiesel production and its economic feasibility. Therefore, it is recommended that the availability of feedstock dominate the site selection decision. Results evaluating the presence of economies of scale in biofuel production have been mixed. However, evidence of experience curve effects (i.e., the reduction of average unit costs as a function of time and/or cumulative output in the industry) have been found in the bioethanol industries of both Brazil and the U.S., demonstrating how both early and sustained governmental support can lead to significant reductions in production costs in the longer-term.

Given the relative insensitivity of biodiesel to economies of scale and the current general lack of a clear and comprehensive government biofuel policy on the African continent, including South Africa, some researchers recommend that it may be preferable to construct a relatively large number of small, decentralised biodiesel plants rather than large-scale centralised biodiesel plants in Africa, as a means of combating risk whilst gaining valuable experience in the production of biodiesel. On-farm biodiesel production in the province of KwaZulu-Natal (KZN) using soybeans (the only biodiesel feedstock identified by the SA industrial biofuels strategy that is grown in significant quantities in KZN) may represent an application of this.

Mixed integer linear programming models were developed in this study to determine the economic feasibility of biodiesel production on both commercial and small-scale farms in the soybean producing regions of KZN. The commercial model simulated observed agricultural land rental rates (estimated at 4.48% of the market value of land) and cropping behaviour of crop farms in the study regions. The model incorporated various alternative crops, crop rotations, tillage techniques, arable land categories and variance-covariance matrices to account for risk in production. The small-scale model was based on the commercial farm model. All data were adjusted to a real 2009/10 basis.

Results indicate that on-farm biodiesel production is currently not economically viable at both the commercial and small-scale level. Under baseline assumptions it was estimated that additional incentive, in the form of a minimum implicit subsidy of R4.37 per litre of biodiesel are required to draw soybean-based biodiesel production into the optimum solution for commercial farms. However, the minimum subsidy for collective smallholder biodiesel production in the absence of a rental market for cropland was conservatively estimated to be nearly three times higher (R12.14/litre). The economic viability of soybean-based biodiesel initiatives are highly dependent on the soybean input price and the soybean oilcake by-product price.

The main conclusions and policy recommendations from this research, therefore, include:

(i) The current set of biofuel policy initiatives outlined by the SA industrial biofuel strategy is inadequate to establish and sustain soybean-based biodiesel production at both the commercial and small-scale farm level in KZN. If the SA government wishes to pursue biofuel ventures, it is imperative that they take a more decisive, comprehensive and long-term policy stance. Therefore, there is a clear need to revise the industrial biofuel strategy, and possibly the (non-binding) Renewable Energy White Paper.

(ii) There is a need to amend the current SA Cooperatives Act (which specifies conditions typical of traditional cooperatives) to allow cooperatives a higher degree of flexibility in their choice of institutional arrangements. Presently, value-adding cooperatives would inevitably fail to attract the capital and expertise needed to process biodiesel owing to ill-defined voting and benefit rights.

(iii) Since South Africa historically imports soybean oilcake and soybean oil, government should rather consider promoting small-scale soybean oil extrusion ventures as a means for value-adding for smallholders. Importantly, these initiatives will likely require considerably less support than soybean-based biodiesel production and may have positive spinoffs for domestic livestock industries.

(iv) Preconditions for smallholder participation in the former homelands include a rental market for cropland, support for development-oriented smallholder organisations like investor-share cooperatives (ISCs) and investment-oriented firms (IOFs) that encourage investment by patrons and strategic equity partners in processing plant, and extension and training for small farmers who typically have little experience in soybean production.

(v) Biofuels are not a panacea and should be used in conjunction with other renewable energy technologies. However, continued research into all aspects of biofuel production and subsequent technology advancements (particularly pertaining to reductions in feedstock costs and/or improved process efficiency), infrastructure development, and prolonged provision of the correct set of government incentives for these initiatives will be vital to the future development of biofuel industries.

Areas for future research include finding alternative applications for the glycerine by-product, establishing cheaper and more efficient small-scale oil extrusion equipment, determining whether biodiesel subsidies (or other forms of public support) are economically justifiable at the national level in South Africa, developing more comprehensive collective smallholder biodiesel production models, and conducting feasibility studies for large-scale continuous flow biodiesel plants, as well as alternative and/or future generation biofuels.

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APPENDIX A: Current Biofuel Production, Future Targets and Policies for Selected Countries

Country	Biofuel Capacity	Future Targets	Main Sources of Biofuel	Explicit Biofuel Policies	Main Trade Policy for Biofuels
Australia	170 million litres of bioethanol	350 million litres of biofuel by 2010	Wheat and molasses	Producer subsidy, capital grants, vehicle standard	Import tariff of $0.31/litre of both bioethanol & biodiesel
Argentina	204 million litres (2006)	5% biofuels by 2010	Soybean	Excise tax credit, mandatory blending, export tax exemption on biofuel blends	Low export tax (5%) for soybean-based biodiesel compared to soybeans (23.5%) & soy oil cake (20%)
Brazil	17.5 billion litres (2006)	25% blending of bioethanol (has been in effect for a long time) & 5% biodiesel from 2013	Sugarcane & soybean	Mandatory blending, capital subsidies & vehicle subsidies	20% ad valorem import tariff on bioethanol (waived in case of domestic shortage)
Canada	240 million litres of bioethanol	5% bioethanol by 2010 & 2% biodiesel by 2012	Maize & wheat	Excise tax credit, mandatory blending, capital subsidies	Import tariff of $0.1228 for bioethanol & $0.11 for biodiesel (lower tariffs & exemptions for select countries)
China	1.2 billion litres of bioethanol (2006)	Data not available	Maize, cassava & sugarcane	Subsidies & tax breaks but only for non-grain feedstock	Import tariff of 30% on bioethanol
Colombia	400 million litres (2006)	10% bioethanol in cities exceeding 500000 people since 2006	Sugarcane & oil palm	Mandatory blending, tax breaks for sugarcane plantations, capital subsidies	Ad valorem import tariff of 15% on bioethanol & 10% on biodiesel
EU	3.6 billion litres of biodiesel (2005) & 1.6 billion litres of bioethanol (2006)	5.75 % of transportation fuel on energy basis by 2010, & 10% by 2020	Rapeseed, sunflower, wheat, sugar beet & barley	Excise tax credit (is being phased out), carbon tax credit, mandatory blending, capital grants & funding for R&D	Ad valorem duty of 6.5% on biodiesel & import tariff of $0.26/litre on bioethanol (latter is waived for some categories of countries)
Indonesia	340 million litres of biodiesel (2006)	10% bioethanol & 10% biodiesel effective April 2006	Oil palm	Mandatory blending & capital subsidies	Lower export tax for processed oils compared to crude palm oil
Japan	Insignificant	360 million litres by 2010 & 10% biofuel by 2030	Imported bioethanol	Excise tax credit	Ad valorem import duty of 23.8% on fuel bioethanol (to be lowered to 10% by 2010)
Malaysia	340 million litres of biodiesel (2006)	5% biodiesel since April 2007	Oil palm	Mandatory blending & capital subsidies	Lower export tax for processed oils compared to crude palm oil
South Africa	Insignificant	Proposed: 2% of national liquid fuel (400million litres) by 2013 (until 2020), including 2% biodiesel & 8% bioethanol blends	Proposed: soybeans, canola, sunflower, sugarcane & sugar beet	Excise tax credit of 40% for biodiesel & 100% tax exemption for small-scale biodiesel producers (<300 000 litres/annum)	N/A
Thailand	330 million litres of bioethanol (2006)	Data not available	Cassava, sugarcane, molasses	Price subsidy & capital subsidies	Import tariff of 2.5 baht/litre & ad valorem tariff of 5% on biodiesel
USA	18.4 billion litres of bioethanol (2006) & 284 million ltres of biodiesel (2005)	36 billion gallons of biofuels by 2022, with 15 billion gallons from maize-based bioethanol & 21 billion gallons of "advanced biofuels"	Maize, & in future cellulosic sources	Excise tax credit, mandatory blending, capital grants, vehicle subsidies	Import tariff of $0.1427/litre of bioethanol plus ad valorem tariff with some exemption for carribbean countries

Sources: Adapted from Rajagopal and Zilberman (2007: 106). Data on Brazil's future mandatory biodiesel blend from Pousa *et al*. (2007:5394); EU blend target for 2020 from Banse *et al*. (2008:119); USA future targets from Senauer (2008:1227); Proposed South African data from DME (2006, 2007).

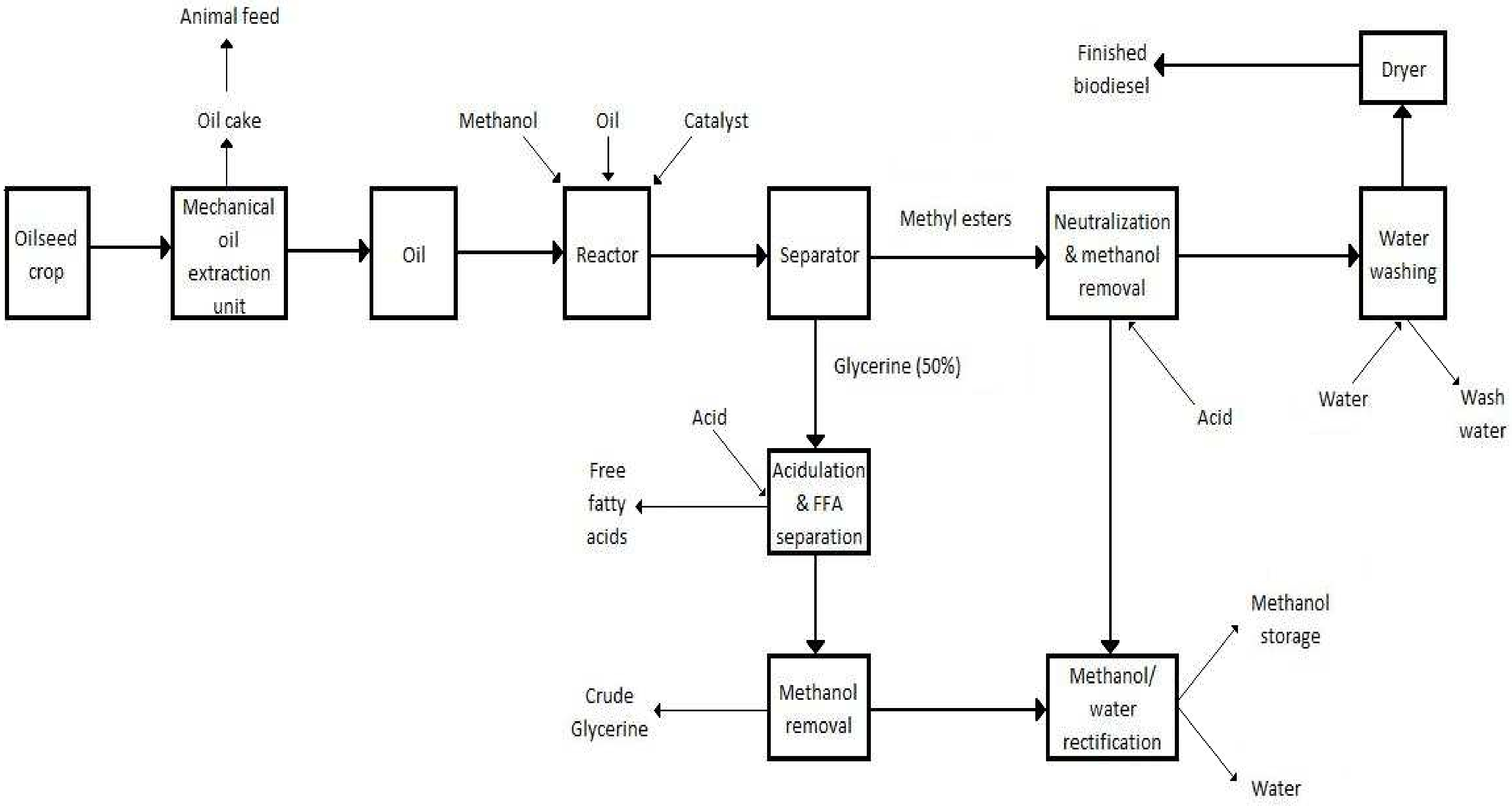

Figure 3.2: Process Flow Chart for Biodiesel Production

Source: Adapted from Van Gerpen and Knothe (2005: 32) and Murugesan *et al*. (2009: 827)

Table 4.1: Summary of Selected Key Aspects of the Baseline Model

	Activities																		
	Soybeans					Maize					......	Dryland Conventional	Irrigation Conventional	Dryland No-Till	Irrigation No-Till	Total Conventional	Total No-Till	Buy Diesel	RHS
	Conventional		No-Till			Conventional		No-Till			......					INT	INT		
	Dryland	Irrigated	Dryland	Irrigated		Dryland	Irrigated	Dryland	Irrigated		......								
	Soygrow	Soygrow	Soygrow	Soygrow	Soysell	Mzgrow	Mzgrow	Mzgrow	Mzgrow	Mzsell	......								
Dland (ha)	1		1			1					......								L 220
Iland (ha)		1		1			1				......								L 220
Soytr (ton)	-2.0	-3.5	-2.08	-3.5	1						......								L 0
Maiztr (ton)						-6	-10	-6.24	-10	1	......								L 0
Soy-Mz Rotation (DRY)	2					-1					......								E 0
Soy-Mz Rotation (IRR)		2					-1				......								E 0
Soy-Mz Rotation (DRY)			2					-1			......								E 0
Soy-Mz Rotation (IRR)				2					-1		......								E 0
:											......								:
:											......								:
:											......								:
Total Dry Conventional	-1					-1					......	1							E 0
Total Irr Conventional		-1					-1				......		1						E 0
Total Dry No-Till			-1					-1			......			1					E 0
Total Irr No-Till				-1					-1		......				1				E 0
Link 1											......	-1	-1			441			G 0
Link 2											......			-1	-1		441		G 0
Choice											......					1	1		E 1
Dieseluse (litre)	60	60	20	35		75	75	20	40		......							-1	L 0
OBJ (R)	-VC	-VC	-VC	-VC	P	-VC	-VC	-VC	-VC	P	......							-6.77	MAX!

Where OBJ = objective function
Dland = dryland
Iland = irrigation land
INT = integer activity
VC = variable cost per hectare
P = product price per ton

APPENDIX B: Summary of Selected Economic Evaluations of Various Biodiesel Plants

	Nelson *et al* . (1994)	Noordam & Withers (1996)	Bender (1999)*	Zhang *et al* . (2003b)	Zhang *et al* . (2003b)	Zhang *et al* . (2003b)	Zhang *et al* . (2003b)	You *et al* . (2008)	You *et al* . (2008)	You *et al* . (2008)
Plant capacity (tons/annum)	100000	7800	10560	8000	8000	8000	8000	8000	30000	100000
Process type	Alkali-catalysed continuous process	Alkali-catalysed batch process	Alkali-catalysed batch process	Alkali-catalysed continuous process	Alkali-catalysed continuous process	Acid-catalysed continuous process	Acid-catalysed continuous process	Alkali-catalysed continuous process	Alkali-catalysed continuous process	Alkali-catalysed continuous process
Raw material ($ million)	Beef Tallow	Rapessed oil	Animal fats	Virgin vegetable oil	Waste cooking oil	Waste cooking oil	Hexane extraction of waste cooking oil	Soybean oil	Soybean oil	Soybean oil
Fixed capital cost ($ million)	Not reported	Not reported	Not reported	1.17	2.33	2.21	2.77	1.17	3.51	10.15
Total capital cost ($ million)	12	Not reported	3.12	1.34	2.68	2.55	3.19	1.35	4.04	11.67
Total manufacturing cost ($ million)	34	5.95	Not reported	6.86	7.08	5.15	5.62	6.89	21.72	67.8
Net annual profit ($ million)	Not reported	Not reported	Not reported	-1.03	-1.14	-0.18	-0.41	-0.024	1.975	8.879
After tax rate of return	Not reported	Not reported	Not reported	- 85.27%	- 51.18%	- 15.63%	- 21.48%	- 10.44%	40.23%	67.38%
Biodiesel break-even price ($/ton)	340	763	420	857	884	644	702	862	724	678
Glycerine credit ($ million)	6	0.9	1.2 (technical-grade glycerine)	0.73	0.68	0.77	0.73	3.19	11.94	39.81

***Only results for one of the biodiesel plants evaluated is reported here.**

Source: Adapted from Zhang *et al*. (2003b: 230) and You *et al*. (2008: 187).

APPENDIX C: Summary of the Effect of Farm Size on Economic Feasibility, Plant Combinations and By-Products

Investment Behaviour															
	Optimisitc Conversion Ratios								**Less Optimisitc Conversion Ratios**						
				Baseline								**Baseline**			
Farm Size (ha)	50	100	200	**440**	1000	1500	2000		50	100	200	**440**	1000	1500	2000
Biodiesel Price (R/litre)	10.72	10.72	10.29	**10.19**	10.06	9.93	9.87		13.34	13.34	12.92	**10.92**	10.21	10.21	10.14
Oil Extrusion															
Plant 1	Yes (1)	Yes (1)	Yes (1)	**Yes (1)**	Yes (2)	No	Yes (1)		Yes (1)	Yes (1)	Yes (1)	**Yes (1)**	Yes (1)	Yes (1)	Yes (2)
Plant 2	Yes (7)	Yes (7)	No	**No**	No	Yes (1)	Yes (1)		Yes (7)	Yes (7)	No	**No**	No	No	No
Sell Soybean Oil (litres)	0	0	0	**0**	0	0	0		0	0	0	**0**	0	0	0
Sell Soybean Oilcake (tons)	7197	7197	181	**343**	685	936	1252		10796	10796	272	**266**	514	514	1028
Biodiesel															
Plant 1 (Low-Tech)	No	No	Yes (1)	**No**	No	No	No		No	No	Yes (1)	**Yes (1)**	No	No	No
Plant 2 (Low-Tech)	No	No	No	**Yes (1)**	No	No	No		No	No	No	**No**	Yes (1)	Yes (1)	No
Plant 3 (High-Tech)	No	No	No	**No**	Yes (1)	Yes (1)	Yes (1)		No	No	No	**No**	No	No	Yes (1)
Plant 4 (High-Tech)	No	No	No	**No**	No	No	No		No	No	No	**No**	No	No	No
Plant 5 (High-Tech)	Yes (1)	Yes (1)	No	**No**	No	No	No		Yes (1)	Yes (1)	No	**No**	No	No	No
Sell Biodiesel (litres)	1809864	1809864	45600	**86184**	172368	235364	314879		1809864	1809864	45600	**44528**	86184	86184	172368
Sell Glycerine (tons)	2390	2390	60	**114**	228	311	416		2390	2390	60	**59**	114	114	228
Buy Soybean (tons)	10556	10510	99	**113**	97	0	0		15848	15802	233	**0**	0	0	0
Objective Function Value (R)	101 014	162 023	250 923	**576 113**	1 272 567	1 908 044	2 526 417		98 322	155 712	251 220	**498 108**	1 074 238	1 588 832	2 103 578
Implicit Subsidy (R/litre)	4.17	4.17	3.74	**3.64**	3.51	3.38	3.32		6.79	6.79	6.37	**4.37**	3.66	3.66	3.59