Biofuel Implications of a Green Economy Transition in the Western Cape Province of South Africa: A System Dynamics Modelling Approach to Biofuel

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering in the Faculty of Engineering at Stellenbosch University

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December 2015

Declaration

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Date: 2015/08/05

Abstract

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September 2015

This study investigates the implications of producing biofuel as part of a green economy transition in the Western Cape Province of South-Africa. Biofuel production was identified as a complex system and different methodologies were reviewed to find the most appropriate technique to analyse complex systems. System Dynamics was identified and used to build a model simulating the effects and potential of biofuel production within the Province, under certain project and policy considerations.

The biofuel model was built with a generic structure that can simulate both bioethanol and biodiesel with different parameters. The model assumes a bioethanol plant, capable of producing 160 million litres per annum to be completed in 2018, using triticale as feedstock. A biodiesel plant with a capacity of 35 million litres per annum will also completed in 2018, using canola as production feedstock.

Different scenarios regarding the energy use of biofuel production were simulated in order to evaluate the feasibility and identify the strategic intervention points, which could strengthen the business case of biofuel production. The national mandatory biofuel blending policy leads to alternative scenarios being simulated, in which the Western Cape Province is externally supplied with biofuel. Recommendations are made on the best approach to follow for the Province to form part of the blending policy, based on pre-determined indicators within the three pillars of sustainability, namely: the economy, environment and social considerations. From the model, it was deduced that feedstock availability and the high capital and operating costs are the major constraining factors in biofuel production. Recommendations are made to mitigate and improve the identified constraints.

A feasible business case (operating without subsidy) was established for bioethanol production within the Province. Under the model assumptions for locally producing bioethanol (using biomass as energy source), an internal rate of return of 23% is estimated, while emissions are reduced by 63% when compared to using coal as the energy source. A medium-large scale biodiesel production facility was not feasible (subsidy of R4.30 per litre) as the adverse effects of emissions and employment creation does not justify the high costs involved. Alternative biodiesel solutions are then proposed, like encouraging the establishment of numerous small-scale on-site biodiesel production facilities. In conclusion, the study limitations and recommendations for future research are discussed. The applicability and effectiveness of using system dynamics for this study is discussed and some recommendations are made to indicate the context in which system dynamics would best be applied.

Uittreksel

Die Implikasies van Biobrandstof in die oorgang na 'n Groen Ekonomie in die Weskaap Provinsie van Suid-Afrika: 'n Stelsel Dinamika Modellerings benadering tot Biobrandstof

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September 2015

Hierdie studie ondersoek die implikasies om biobrandstof produksie as deel van die oorgangs fase na 'n groen ekonomie in die Wes Kaap Provinsie van Suid Afrika te bewerkstellig. Biobrandstof produksie word geïdentifiseer as 'n komplekse sisteem en verskillende metodologieë was ondersoek om die mees geskikte benadering tot die evaluering van komplekse sisteme te vind. Stelsel dinamika was gevolglik geïdentifiseer en gebruik om 'n model te bou. Die model simuleer die uitwerking en potensiaal van biobrandstof produksie in die Provinsie onder sekere projek- en beleid inagnemings.

'n Generiese struktuur is gebruik in die biobrandstof model, sodat die produksie van bio-etanol en biodiesel gesimuleer kan word met verskillende parameters. Die model neem aan dat 'n bio-etanol produksie fasiliteit met 'n kapasiteit van

160 miljoen liter per jaar in 2018 voltooi sal wees. Vir biodiesel word ‘n fasiliteit met ‘n kapasiteit van 35 miljoen liter per jaar voorgestel, wat ook in 2018 voltooi sal wees. Die roumateriaal vir die biobrandstof produksie, is korog (“triticale”) en canola vir bio-etanol en biodiesel onderskeidelik.

Verskillende scenario’s rondom die gebruik van energie in biobrandstof produksie was gesimuleer om sodoende die lewensvatbaarheid te ondersoek en strategiese ingrypings punte te identifiseer wat die finansiële vooruitsig van biobrandstof kan verbeter. Die nasionale verpligte biobrandstof vermengings beleid het daartoe gelei dat ‘n alternatiewe scenario, waar die Wes Kaap Provinsie deur ‘n eksterne biobrandstof-bron voorsien word, ook ondersoek moet word. Aanbevelings word gemaak oor die beste benadering om te verseker dat die Provinsie deel uit maak van die verpligte vermengings beleid, aan die hand van sekere vooraf bepaalde aanduiders binne die drie pilare van volhoubaarheid, naamlik: die ekonomie, die omgewing en sosiale faktore. Uit die model kon dit afgelei word dat die beskikbaarheid van roumateriaal, die kapitaal uitleg asook operasionele kostes die grootste beperkings op biobrandstof produksie sal wees. Aanbevelings word gemaak om die beperkings te bestuur en verbeter.

‘n Lewensvatbare besigheidsaak is vir die produksie van bio-etanol in die Provinsie bevestig. Die aannames in die model rondom die plaaslike vervaardiging (deur biomassa as energiebron te gebruik) het ‘n verwagte interne opbrengskoers (“IRR”) van 23% getoon, terwyl emissies met tot 63% verminder in vergelyking met die gebruik van steenkool as energie bron. ‘n Medium-groot skaal biodiesel produksie fasiliteit is nie lewensvatbaar nie. Met ‘n minimum subsidie van R4.30 per liter wat benodig word, kan die positiewe omgewings en sosiale aspekte nie die hoë kostes regverdig nie. Alternatiewe biodiesel produksie oplossings word voorgestel soos om menigte klein-skaalse fasiliteite ter plaatse op te rig. Die studie word afgesluit deur die tekortkominge en aanbevelings van die studie vir toekomstige navorsing te noem. Die toepaslikheid en effektiwiteit van stelsel dinamika modellering vir hierdie studie word ook bespreek en aanbevelings word gemaak rondom die omstandighede waarin stelsel dinamika die beste toegepas kan word.

Acknowledgements

I would like to express my sincere gratitude to the following people and organisation:

My study-leaders Prof. Alan Brent and Dr. Josephine Musango for their great insights, guidance, support and the wonderful opportunities they provided.

My best friend Donné Terblans for her continued support, patience and relentless efforts to keep me motivated.

My family for their endless financial and emotional support and encouragement throughout my time at Stellenbosch University.

The National Research Foundation (NRF) for partly funding this study.

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List of Acronyms

ABM	Agent Based Modelling
AFMA	Animal Feed Manufacturers Association
BFP	Basic Fuel Price
CAPEX	Capital Expenditure
CAS	Complex Adaptive System
CGE	Computable General Equilibrium
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DES	Discrete Event Simulation
FAME	Fatty Acid Methyl Esters
GDP	Gross Domestic Product
GHG	Green House Gasses
GIS	Geographic Information Systems
HDSA	Historically Disadvantaged South African
I-O	Input-Output
IRR	Internal Rate of Return
LRAD	Land Redistribution for Agricultural Development
LP	Linear Programming
MLP	Multi-Level Perspective
NDP	National Development Plan
NLP	Non-Local Production
NERSA	National Energy Regulator of South Africa
OPEX	Operating Expenditure
PPA	Petroleum Products Amendment act
PPP	Public-Private Partnerships

REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROA	Return On Assets
SA	South Africa
SAM	Social Accounting Matrix
SD	System Dynamics
SES	Social-Ecological System
SMME	Small Medium and Micro Enterprises
SNM	Strategic Niche Management
TIS	Technological Innovations Systems
TM	Transition Management
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nation Environment Programme
WCED	World Commission on Environment and Development
WCG	Western Cape Government

Chapter 1

Introduction

The ever increasing pace of industrialisation and urbanisation of the world has led to a dramatic increase in the economic welfare of a large group of the global population, resulting in an expanded middle class population. With more people now tapping into the global resource pool, natural resources are placed under extreme pressure. This necessitated the development of a number of governing bodies, policies and strategies to regulate and mitigate the depletion of global resources and the effect of global warming. Sustainable development is one of the concepts developed to conserve natural resources, while alleviating poverty, and a green economy is one of the implementation techniques used to drive sustainable development. The following literature aims to provide background on how biofuel came to be one of the focus areas as part of sustainable development and the transition to a green economy in the Western Cape Province of South Africa. The relevant research questions and objectives are also identified in order to evaluate the implementation of biofuel production.

1.1 Background and Context

Over the last two decades, sustainable development has been incorporated and endorsed as a guiding principle for economic and environmental welfare by numerous corporations, governments and civil society. It was popularised by a report published by the World Commission on Environment and Development (WCED) in 1987. The report *"Our Common Future"*, also known as the Brundtland report stated one of the first and most well known definitions of sustainable development, after noting that economic growth cannot be decoupled from sustaining a healthy society, while preserving the environment. The WCED defined sustainable development as: *"development that meets the needs of the present without compromising* *the ability of future generations to meet their own needs"* (Brundtland *et al.*, 1987).

Sustainable development recognises the complete interdependence between economy, human society and environment as depicted in Figure 1.1. This close interdependence has lead to the development of numerous concepts, techniques and policies to facilitate and encourage the implementation of sustainable development. One of the more recent concepts towards becoming a sustainable civilisation involves the transition to a green economy. According to United Nation Environment Programme (UNEP), a green economy is *"an economy that will result in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities"* (United Nations Environment Programme, 2010).

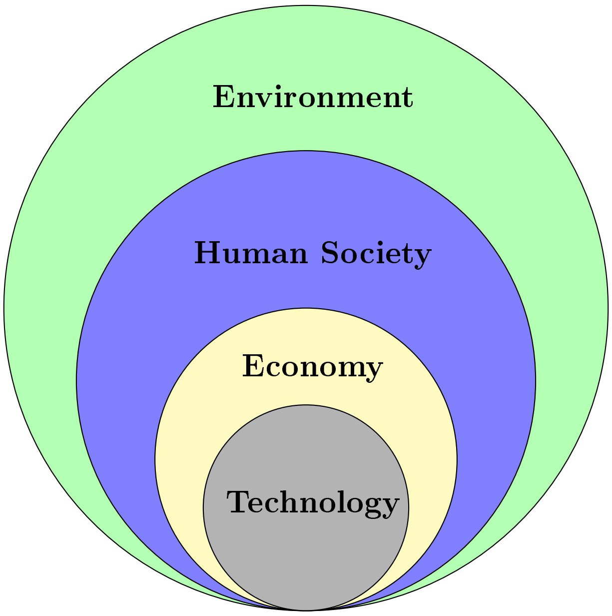

Figure 1.1: Integrating the three pillars of sustainability and technology (Adapted from: Anstey and Hetherington (2014))

Sustainable development is implemented differently across the world, based on the fact that most role players find themselves in different geographic, social, economic and political environments. This is evident from the difference in approaches followed by developed countries and developing countries. Developing countries tend to emphasise poverty alleviation over something like reduction of pollution. South Africa (SA), being a third world country, relies mainly on the use and exportation of natural resources to drive the economy and sustain the population's livelihood. The country is thus greatly dependent on the efficiency of its resource utilisation, which makes the green economy principle an ideal approach to implementing sustainable development in SA. In order to facilitate the transition to a green economy and becoming more sustainable, the South African Government issued the National Development Plan (NDP). The NDP is a document describing the road ahead to transform the South African economy to a low carbon, environmentally sustainable economy (National planning Commission, 2012).

The NDP advocates a transition from policies to processes to actions, where policies are developed on national level and applied to each of the nine provinces in a top down approach. Provincial bodies then further develop the processes and actions, to suit their provinces' specific demographic, environmental and social needs (to best implement the policies). Diversification of the fuel supply mix has been a priority since the national government recognised the need for increased efficiency and reduced green house gas (GHG) emissions from the transport sector in 1998, when a white paper on energy policy was published (Department of Minerals and Energy, 1998, 2007). This national policy formation lead to the instating of a governmental mandate (effective October 2015), stipulating that the current national fuel pool should be blended with 2% biofuel by volume. In order to meet this demand for an estimated 400 million litres of biofuel per year, four bioethanol and biodiesel production plants have been approved for construction in KwaZulu Natal, Free State, Gauteng and Eastern Cape Provinces. The mandate requires the blending of petrol fuel with between 2% - 10% bioethanol (E2-E10) and diesel with a minimum of 5% biodiesel (B5) (Department of Energy, 2012).

As part of the provincial action plan, the Western Cape Government (WCG) created the *"Green is Smart"* strategy framework to act as a roadmap for the Western Cape Province *"to become the leading green economic hub on the African continent"* (Western Cape Government, 2013). The framework identifies clean energy and transport efficiency as major role players in the transition to a green economy. This will assist in facilitating the use and production of biofuels by the public and private sectors in order for the Western Cape Province to be self-sufficient in responding to the mandatory blending policy. The Western Cape Province is not explicitly included in the national biofuel strategy and has since conducted numerous independent studies in order to develop an optimum approach to the production of biofuel within the Western Cape Province. The studies have focused on crop selection, agricultural implications, and identifying key drivers and role players.

1.2 Problem Statement

The successful development and implementation of biofuel policies in other countries such as Brazil and the United States of America have set the example which lead to good policy formation and even a number of small scale operational plants in SA. Although policies and strategies are in place to attract investment into biofuel, some uncertainty exists regarding the specific impacts and potential of commercial biofuel production in the Western Cape Province.

The Western Cape Province is unique in the sense that it is a winter rainfall region and therefore the crops available for biofuel- and food production differ from the other areas where feasible biofuel operations have been implemented. The economy of the Western Cape Province is driven by the exportation of agricultural products. The agriculture sector and the well being of the economy is thus sensitive to climate change and changes in rainfall patterns. Recent years have seen an increase in various temperature indices (specifically minimum temperatures observed) and future predictions estimate that this trend will continue, along with a shift in rainfall patterns (Provincial Government of the Western Cape, 2011; Tadross and Johnson, 2012).

Due to the sensitivity and dependence of the Province's economy and biofuel production on the availability of agricultural crops, availability of investment, water allocation and land availability amongst others, it is imperative that all of the drivers and actors influencing biofuel production are identified on a quantitative and qualitative level.

In order to assess the viability of biofuel production and complying with the mandatory blending policy, a variety of indicators have to be investigated. Past studies evaluated biofuel projects at the hand of certain static variables, and although this gives a good indication of the investment required and expected returns, it does not take the dynamic factors, effects and feedback between exogenous and endogenous variables into account. There is thus a need for a model that can indicate the complex interactions and the possible outcomes of commercial biofuel production on the identified sectors.

A recent study identified the economies of scale and feedstock requirements for biofuel production in the Western Cape Province (Green Cape, 2015). The study further identified key influencing factors that will ultimately determine the strength of the business case for biofuel production in the Province. The most influential drivers were found to be the basic fuel price (BFP) and the feedstock cost. It is however important to take a variety of scenarios into account and simulate how different local production scenarios can affect the business case and other key areas like employment and emissions.

Alternatively to local production, a scenario should be considered in which biofuels will be purchased from existing[1] biofuel plants in order to reach the mandatory blending percentages. Although the blending policy does not require all refineries to blend biofuel, the alternative case should be considered because the Western Cape Province could play a vital role in biofuel blending. The Province is home to two of the country's six refineries and contributes roughly 20% of the total fuel supply (South African Petroleum Industry Association, 2015).

The aim of the research is thus to identify key drivers and factors influencing the biofuel sector in the Western Cape Province, as well as the interaction between these drivers. Possible scenarios in which the Western Cape Province will form part of the mandatory blending requirement need to be evaluated and the effect of these scenarios on certain key indicators used to clarify the best approach to incorporate a biofuel industry within the Province. A comparison of the identified indicators under different scenarios can be used to identify key intervention points for strategic decision making. With these intervention points in mind, some recommendations should be given on ways to strengthen the business case of biofuel production and inform policy- and decision-makers within the Province.

1.3 Research Objectives

As discussed above, there are complex interactions involved in the production of biofuel. In analysing the business case for biofuel in the Western Cape Province, a variety of factors will have to considered, some of which cannot be accurately foreseen or forecasted by making use of linear thinking. The objectives of this study are thus as follows:

i. Identify drivers, constraints and opportunities of commercial biofuel production in general and specifically for the Western Cape Province;

ii. Investigate methods used to inform strategic decision making and use the most appropriate method to provide insight into the management and implementation strategies for the business case of biofuel production in the Western Cape Province;

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[1] It is assumed that biofuel production facilities that have been granted licenses for biofuel production are operational.

iii. Make recommendations to guide strategic decision making and intervention strategies for the way forward for biofuels in the Western Cape Province; and

iv. Conclude and make recommendations on the usefulness of the method used to inform strategy and decision making.

1.4 Research Approach

This section describes the research process that was used to address the problem statement and research objectives. Firstly, the current pool of theoretical knowledge was reviewed in order to identify the gaps in the research. Various methods that can be used to describe and encapsulate complex systems were also evaluated, along with the theoretical knowledge relating to transition management. Upon reviewing approaches to deal with complexity, the most appropriate method was selected to simulate biofuel production. This method could then be used to quantitatively and qualitatively describe the effect of biofuel production within the Province, which ultimately assisted in identifying key drivers and strategic intervention points.

In order to successfully complete the research process, a variety of possible scenarios were simulated. As mentioned earlier local production scenarios were compared to a scenario where biofuel is brought in from biofuel production plants elsewhere in the country in order to asses the feasibility and effects of the Western Cape Province forming part of the mandatory blending policy. By comparing the effects on key indicators identified, it was possible to reach a conclusion on the feasibility and the way forward for biofuel production in the Western Cape Province.

Recommendations are made on how any adverse effects of biofuel production can be mitigated, as well as the critical factors that should be monitored and managed to strengthen the business case and promote the transition to a green economy.

Table 1.1 illustrates the research approach or process and clarifies the objectives to be achieved and addressed by each chapter. Supporting arguments and information are given in addition to reaching the objectives in each chapter.

Table 1.1: Objectives of chapters

Chapter	Chapter Objective
Chapter 2	*Literature Review:* • Study the literature on biofuel and approaches to deal with complexity and complex systems (including modelling techniques). • Study the literature on transition theory in order to identify the best approach to evaluate and provide insight into policies and strategic intervention points to facilitate change in socio-technical systems. • Determine the best approach to model the outcomes and effects of biofuel production in the Western Cape Province.
Chapter 3	*Modelling Approach:* • Identify drivers and causal effects of biofuel production. • Build a model to analyse the business case of biofuel production as part of the green economy transition.
Chapter 4	*Modelling Outcome:* • Indicate simulation results. • Discuss simulation results and identify strategic intervention points.
Chapter 5	*Conclusion:* • Give insight into the effect of managerial and implementation strategies on the business case of biofuel production. • Comment and make recommendations on the feasibility and the way forward for biofuel production in the Western Cape Province. • Comment on the applicability and effectiveness of the chosen modelling technique.

Table 1.2 indicates how the research objectives are met in the respective chapters of this study.

Table 1.2: Reaching research objectives

Chapter	Chapter Topic	Research Objective
2	Literature Review	Research Approach & ii
3	Modelling Approach	i & ii
4	Modelling Outcomes	ii & iii
5	Conclusion	iii & iv

This section provided background and an introduction to the biofuel sector in SA, while also highlighting the opportunities for biofuel production in the Western Cape Province specifically. The research objectives and proposed research approach are indicated and discussed.

It can be concluded that in order to quantitatively analyse the business case and adverse effects of biofuel production in the Western Cape Province, it will first be necessary to gain comprehensive insight and understanding into past research and developments in biofuel production and analyses of complex socio-technical systems through modelling. Chapter 2 reviews the relevant literature in order to establish a sound theoretical base. Upon reviewing the literature, an appropriate approach to simulate the effects of biofuel production in the Western Cape Province could be identified.

Chapter 2

Literature Review

In order to ensure objectivity and transparency in the literature review, it is firstly necessary to describe the methodology behind the literature review. A review of the current knowledge pool is conducted and the available information investigated in order to come to accurate conclusions regarding the context and influencing factors involved in biofuel production and policies. Complex systems theory and management of such systems are also considered. Lastly, various modelling techniques are reviewed and compared in order to ensure that the most appropriate approach to deal with the complexities involved in biofuel production is selected.

2.1 Research Methodology

In order to gain complete insight into the current knowledge available, a combination of literature review processes are used. This includes a systematic review of available literature whereby the context and origin of biofuel production and policies are investigated. The complex and intricate causal nature of biofuel requires an in-depth analysis of systems thinking and complex systems theory. The literature on transition theory is systematically reviewed in order to investigate and describe the effect of biofuel production on the transition towards a green economy. A conceptual review process is used to give an overview of some of the aspects involved in the modelling of biofuel production and its complex interactions.

The descriptive research approach, which sets out to indicate and explore the potential and effects of producing biofuel within the Western Cape Province, is indicated in Figure 2.1.

The research is mainly conducted by following an ancestral approach where rel-

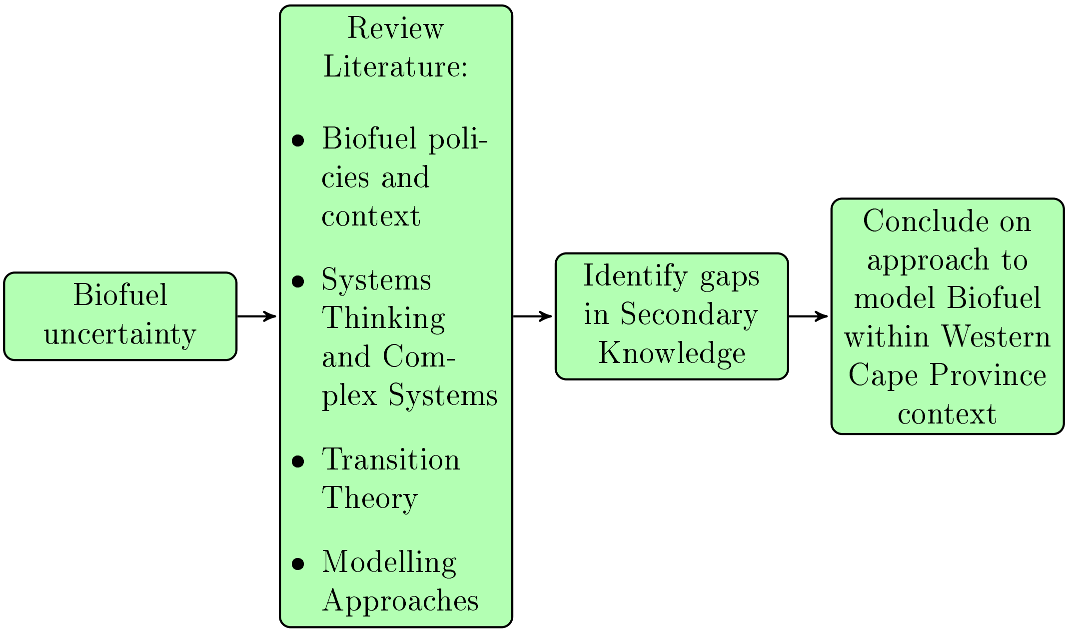

Figure 2.1: Research Process

evantly cited articles were tracked through secondary channels and often making use of triangulation to ensure a high level of reliability, validity, sensitivity and objectivity. The research has limitations in that some of the sources used for dealing with complexity focuses on a single method and thus showed some bias towards the said method. The critique of the literature does however ensure objectivity. The lack of operational large scale biofuel production facilities has lead to operational parameters and information on biofuel production to be relatively underdeveloped and inconsistent, which could further limit the accuracy of the outcome. The model is however designed to be as generic as possible in order for it to be updated as the knowledge pool expands and actual parameters become available.

The following keywords were used in different combinations to find the relevant literature in the majority of English books and published journals, as well as the local and national government documents, where needed (some of which were unpublished but distributed as draft papers): biofuel, Western Cape, Green Economy, systems thinking, Complex systems, Complicated systems, transition theory, modelling, climate change, sustainability transition, renewable energy, biofuel, bioethanol, biodiesel.

2.2 Biofuels within the South African Context

The need for diversifying SA's energy supply mix has long been a topic of concern and was initiated by the release of the *White Paper on Energy Policy of the Republic of South Africa* in 1998. This document sets the government's vision in terms of policies, principles, strategic goals and objectives to promote and implement renewable energy in SA. The diversification of the fuel supply mix is one of the government's key goals and has been driven by the large expenditure owed to dollar-denominated imported fuels burdening the economy (Department of Minerals and Energy, 1998).

In line with the transition to renewable energies, the government set a target of 10,000 GWh of the total energy consumption to be produced by renewable energy sources by 2013. These renewable sources mainly include biomass, wind, solar and small-scale hydro energy. The target was aimed at the power generation sector as well as non-electrical technologies like water heating and biofuels[1]. The large-scale utilisation of renewable energies could have numerous advantages, including reduced emissions of GHG to contribute to an improved local and global environment, the promotion of small medium and micro enterprises (SMMEs) to alleviate the unemployment pressures in the country and introducing a competition element in energy production which is likely to attract private investments to the commercialisation of local renewable energy production.

Noting that 30% of SA's energy consumption by energy content and 70% by value was consumed within the transport sector in 2003, biofuel was identified to be one of the key role players in reaching the renewable energy target. The Petroleum Products Amendment (PPA) Act (No. 58 of 2004), authorised the Minister of Minerals and Energy to require licensed liquid fuel producers to supply and sell petroleum products produced from "vegetable matter". In 2005 the national treasury revised the incentives to produce biofuel and approved a 40% fuel levy exemption for biodiesel, while small-scale biodiesel producers will enjoy a 100% exemption. The latest draft proposal suggests a 50% fuel levy exemption for biodiesel, while no rebate has been instituted for bioethanol, as it falls outside the fuel tax net (The Department of Energy, 2014).

The National Biofuels Industrial strategy was released in 2007 and mandates the blending of the national liquid fuel supply with 2% (roughly equivalent to 400 million litres per annum) of biofuels by October 2015. The stipulated 2% blending

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[1] Biofuels are renewable energy sources made from biological matter and is divided into two main products namely bioethanol and biodiesel (More information on biofuel can be found in Appendix A).

policy was revised from an initial 4.5%, as it was found that a 2% penetration level can be reached, without raising concern regarding the nations food security or notably affecting the energy density of the fuel mixture. Based on the fact that biofuel can be produced using biological matter, certain crops like Jatropha [2] and maize were excluded as feedstock, to ensure that the production of biofuel does not have negative environmental impacts or competes with food sources . The strategy proposes sugar cane and sugar beet for bioethanol production and sunflower, canola and soya beans for biodiesel (Department of Minerals and Energy, 2007).

It is worth noting that the blending mandate does not require every litre of petroleum based fuel to be blended with biofuel. Oil companies will however be obliged to purchase the biofuel available from producers (assuming that they meet the quality standards). To date there are no approved commercial activities aiming to produce biofuel within the Western Cape Province, but the fact that an estimated 20% of the country's fuel supply is refined in the Western Cape Province places it in the position where it can play a key role in complying with the blending mandate. If the Province were to form part of the mandate, without having local biofuel production facilities, the Province will be in a position where it has to purchase biofuels from existing biofuel plants elsewhere in the country. This option could prove to be costly and counter-productive. Further motivation for a local biofuel production scenario can be found in the fact that the WCG mentions the use of clean energy in the motor vehicle sector as part of its *"Green is Smart"* framework in order to guide the uptake of clean energy.

To facilitate the drive towards locally produced clean energy, numerous studies have been done to investigate feasible options for the Western Cape Province to produce its own biofuel. Triticale and canola were identified to be most feasible feedstocks to produce bioethanol and biodiesel respectively when considering the current crop production policies (Davis-Knight *et al.*, 2008; Amigun *et al.*, 2011). Although recent studies have evaluated the business case for biofuel production in the Western Cape Province, there is room for a model that looks at biofuel production and policies in a more holistic manner. This will entail considering and comparing the local production scenario with an alternative scenario (i.e. buying biofuels from established plants elsewhere in the country). This holistic picture should also provide information on the adverse effects of biofuel production in terms of various indicators like job creation, land implications, emissions and the bottom line cost involved to comply with mandatory blending regulations. By comparing the different scenarios, it is possible to establish the resource requirements and the extent to which the mandatory blending policy can be complied

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[2] Jatropha is an alien invasive species with poisonous pods and leaves.

with. The impact on the local environment, society and economy is also indicated.

Growth within the biofuel industry has been driven by a variety of factors, including support for renewable energy and more environmentally friendly energy sources, while boosting the local agricultural sector and attempting to limit global warming. It is however evident that a vast network of resources, policies, regulations and drivers are involved in the biofuel industry. Some of the major concerns regarding the commercial production of biofuel include water limitations, food security, land value, land availability, biofuel quality, crop selection, fuel levies and subsidies and its effects on the agricultural sector (Elbehri *et al.*, 2013).

Sukkasi *et al.* (2010) mentions that although biofuel is a renewable and alternative fuel that can contribute towards sustainable development, the full potential of biofuel will depend on how production, usage and other activities affect the economy, society and the environment. Sukkasi *et al.* (2010) further states that biofuel offers numerous advantages to communities on a local, national and global level. Biofuel developments are however complex and will affect many stakeholders, especially fragile environments and poor rural areas in the case of developing countries. Careful planning and management is thus important to ensure that biofuel production and utilisation contribute towards sustainable development and that unexpected exogenous problems do not undermine this contribution.

Developing countries are especially vulnerable and have an increased number of complexities because of the concerns regarding land concessions, livelihood of local communities and farmers hoping to gain from the biofuel market. Large-scale biofuel development is thus multi-staged and involves stakeholders from many sectors. The stages range from policy drafting to ensure land availability, to feedstock crop planting, production, standardisation and distribution. An in-depth multidimensional analysis of biofuel production can thus help to identify all possible risks and outcomes upfront, while allowing for steps to be taken to ensure that biofuel production contributes towards sustainability (Sukkasi *et al.*, 2010).

The implementation of policies and strategies can have far reaching effects, often beyond any foreseeable forecasts and predictions. These unpredictable outcomes are a result of complex interactions between actors involved, which cannot be understood in a linear fashion. Thus, complex non-linear scenarios, as is the case with biofuel production in the Western Cape Province, requires modelling techniques to be used along with systems thinking in order to assist in policy development. Modelling can be used to evaluate the qualitative and quantitative effects on the resources involved in various scenarios. By studying the quantitative predictions within the context of a transition to a green economy, it will be possible to provide insight and assist in developing an effective and successful approach to commercial biofuel production within the Western Cape Province.

The following areas are investigated in order to overcome the problem of uncertainty surrounding feedstock capacity, production capacity and investment requirements with regards to biofuel in the Western Cape Province:

i. Growing fuel demand;

ii. Feedstock and land available for biofuel production;

iii. Biofuel production capacity;

iv. Investment requirements;

v. Costs involved to comply with mandatory blending policy (if biofuel is not produced locally);

vi. Biofuel profitability; and

vii. Key drivers to influence and strengthen the business case for biofuel production.

The areas identified above are only some of the drivers that form part of the larger biofuel system in the Western Cape Province and they are mentioned here to illustrate the complex nature and extent of the factors involved in biofuel production. A detailed explanation of the inherent behaviours of all the factors and how they relate to one another is given in Chapter 3. This variety of drivers indicate that there is a need for systems thinking and a complex systems approach when studying biofuels.

2.3 Systems Thinking, Complicated and Complex Systems

Loorbach (2010) mentions that society is becoming increasingly complex on three different levels, where the first is the level of society itself, secondly, the increasing complexity of the problems and lastly, the way in which these problems are managed or governed. He proposes systems thinking as an approach to encapsulate the complexities of persistent problems where, society itself and the possible solution is likely to lead to further complexity and can thus not be solved by short-term solutions. These persistent problems are not structured and their causes can be found in various domains with varying levels of complexity and different actors. It can thus be said that an analytical approach to deal with these issues will not suffice. Systems thinking or complex systems theory should be used as a language to address complex interactions and patterns between components in these systems (Loorbach, 2010).

Based on the interconnectedness and interdependence of the multiple factors that influence biofuel production, it is necessary to investigate the approaches that can deal with complexity in a holistic manner. The first of these approaches is from a systems thinking perspective. According to Afgan and Carvalho (2002), system analysis is a philosophical approach and a collection of techniques (explicitly including simulation) to address issues when dealing with complex systems. Systems thinking provides a holistic approach through the use and solving of mathematical models to identify and solve key characteristics of a complex system. Systems thinking is defined by Maani and Cavana (2007) to be a scientific field of knowledge used to understand change and complexity through a study of dynamic cause and effect over time.

Systems thinking is based on some general principles as explained by Anderson and Johnson (1997):

i. Thinking of the “big picture”;
ii. Balancing short-term and long-term perspectives;
iii. Recognising dynamic, complex and interdependent nature of systems;
iv. Taking measurable and non-measurable factors into account;
v. Noting the presence of feedback loops;
vi. Distinguishing between cause and symptom; and
vii. Making use of either-or thinking.

Systems thinking is thus an approach that considers all possible influencing factors and establishes their interconnectedness and effects largely by means of modelling. The phases of the modelling approach involved is indicated in Figure 2.2.

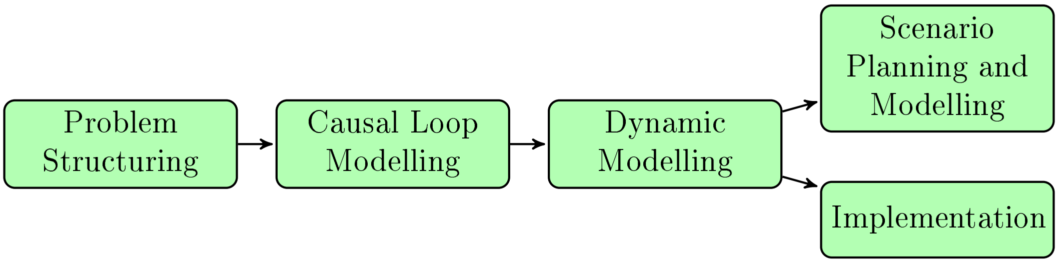

Figure 2.2: Systems Thinking Phases (Maani and Cavana, 2007)

Systems thinking can be used to deal with both complicated and complex systems. To apply systems thinking correctly in these cases, it is first necessary to have an understanding of the constituents that form part of a complicated system. According to Noor (2011), a complicated system consists of functional components that can be broken into subsystems which are well defined and can be well understood. Norman (2011) takes a different perspective and states that a complicated system can be described as one that contains variables which can be combined in a linear and predictable manner in order to distinguish their effect from the overall impact of the system and would thus enable one to look at a particular variable and its inputs and outputs in isolation.

It can be deduced that although complicated systems theory is very powerful and can lead to accurate models, it is unlikely that it will consistently lead to accurate real life estimations. It is therefore necessary to use complex systems theory to represent reality more accurately. This is supported by Norman (2011), who defines a complex system as follows:

> *"A system is complex if, in addition to non-linear relationships, it is characterised by multiple indefinable variables interacting in indefinable, unstable and ultimately unknowable ways so that no system of linear equations can represent the reality."*

Gharajedaghi (2011) states that complex systems differ from complicated systems, which can be approached analytically. Complex systems frequently display counter-intuitive behaviour, based on the understanding that cause and effect can be separated in time and space and may display circular behaviour. Events in complex systems often have more than one effect and the importance of that effect may change over time. Realising the level of chaotic and radical behaviour that may arise from complex and counter-intuitive systems, they are at times mistakenly approached by making use of chaos theory (Gharajedaghi, 2011).

Norman (2011) is of the opinion that the main distinguishing factor between a chaotic and complex system is that the outcome of a complex system can still be predicted, regardless of the complex interactions. A chaotic system, in contrast, often has variables with relatively simple interactions, yet it is impossible to accurately predict the outcome of the system.

The inherit known non-linear and multi-loop nature of social, economic and environmental interaction makes complexity theory very applicable to modelling of real life situations (Norman, 2011; Gharajedaghi, 2011). To develop a model that can accurately estimate the outcome of real life scenarios, it is important to note some key characteristics that define a complex system. According to Radford (2008) these characteristics are:

i. Numerous variables interacting simultaneously;

ii. Non-linear and dynamic causal interactions;

iii. Vague boundaries; and

iv. Unforeseeable new variables arising.

Noting that these characteristics are present in most natural and social systems and are therefore classified as complex systems, additional complexity is added when the interaction between these social and natural systems are considered (Berkes and Folke, 1998). A complex system containing within it interacting and complex natural and social systems is thus classified as a Social-Ecological System (SES). Seeing this on a generic level, Dawson *et al.* (2010) describes a SES to be a form of Complex Adaptive System (CAS), where a CAS consists of a dynamic system of agents that are acting independently and alongside each other, while continuously reacting and responding to the environment and actions of other actors. By studying a CAS, it may be possible to explain how the complex structures and patterns of interaction arise through simple, yet powerful system wide rules that guide change (Folke, 2006). This provides the basis for identifying sustainable development as a form of SES and using the relevant concepts to give an accurate prediction of where change in this area may lead.

It is important to note that there are limitations in the management of complex systems, as cause and effect are more often than not disproportional to each other. Complex systems further tend to resist change although certain critical points or unexpected "regime shifts" may occur. This systemic resistance means that most complex systems self-organise and it would thus prove costly to try and force change. The most appropriate way to manage a complex system is to guide the self-organisation or facilitate the coordination of efforts (Helbing and Balietti, 2013). According to Loorbach (2010), this can only be done if the patterns and mechanisms involved in a system are fully understood and insight has been gained into the feasibility of directing and influencing it.

2.4 Transition to Sustainability

It has been noted that sustainable development and the implementation of it, constitutes a complex system based on the variety of interacting actors and networks involved. Even though the concept of sustainability is not new and has long been a global goal, a number of transformations have to occur in order to realise this ideal. Sustainability transition involves processes that are multi-dimensional and long-term based, which can be used to cause a shift in the socio-technical systems to a more sustainable approach to utilising resources (Markard *et al.*, 2012). The world is thus in a global transition that cannot depend on a spontaneous change to happen, but should in fact be socially guided (Grin *et al.*, 2010).

Loorbach (2010) notes that even tough societal consensus is often reached on complex topics like sustainable development in order to make policy decisions, the top-down government steered and free market approaches are outdated and do not effectively facilitate societal change. In order to socially guide such a transition with the needed sense of urgency, it is required that role players have a good understanding of the conceptual approaches to dealing with socio-technical transitions (Markard *et al.*, 2012). The approaches are discussed in Table 2.1 and include Transition Management (TM), Strategic Niche Management (SNM), Multi-Level Perspective (MLP) and Technological Innovations Systems (TIS).

It is likely that all four of the approaches will be combined when managing the transition to a green economy, seeing as it relies on new technologies and a multitude of actors with interdependencies which will have to be managed carefully in order to achieve the transition without having to enforce any rigid principles. It has been noted that innovation requires a significant amount of change from the parties involved and that it is often difficult for people to engage on this level of change. People are normally inclined to resist change and tend to adhere to habitual and routine behaviour. The transition to a green economy could thus be accelerated if the obstacles contributing to the resistance to change are thoroughly understood. According to Hon *et al.* (2014), the obstacles include: reluctance to relinquish control, unwillingness to think differently, inability to deal with change,

Table 2.1: Approaches to transitioning

Transition Management	• A combination of technological transition and complex systems theory (Markard *et al.*, 2012). • Based on a natural governance principle where transitions are to be managed through having long term objectives, interventions and participation from stakeholders. • Managed without becoming too prescriptive or losing the complexity of the system by being excessively rigid in the management thereof (Loorbach, 2010).
Strategic Niche Management	• Niches contribute to fundamental transitions in socio-technical scenarios as they often bring about a radical change. • SNM is an approach used to gain the full potential of new technologies by adopting them early enough. • Can only be done if the market selection and stability of the niche is managed and understood completely (Witkamp *et al.*, 2011).
Multi-Level Perspective	• Middle-range theory that describes the overall socio-technical transition, in terms of three analytical levels: niches, regimes and the exogenous landscapes (Geels, 2011). • Takes a holistic approach.
Technological Innovations Systems	• Uses the potential of emerging actors to contribute in the transitions towards a predetermined goal (Coenen *et al.*, 2012). • Looks at emerging socio-technical configurations.

intolerance to the learning curve or time involved, preference for low-level stimulation, reluctance to give up habits, and costs involved.

Considering the obstacles mentioned and the context of biofuel, it can be said that the costs involved are likely to be one of the most important factors in the transition to biofuel production. Elbehri *et al.* (2013) identifies economic feasibility to be one of the key indicators in the sustainability of biofuel production. The capital required, along with the lack of incentive, competing markets and a weak business case deters investors and farmers from making the investment into biofuel production. It is thus clear that an intervention or implementation strategy is required that will strengthen the business case and indicate the opportunities within the biofuel sector of the Western Cape Province to facilitate the uptake of biofuel production as part of the transition to a green economy.

2.5 Dealing with Complexity

In order to accurately analyse the the business case and potential of the Western Cape Province to produce biofuel, it is important that the correct approach be used to predict the possible outcomes of the SES. Over the years, a variety of methods have become available to researchers, noting that they are not all equally useful under the same conditions as most modelling approaches were developed for a specific application. The pitfalls and advantages of relevant methods are investigated in order to select the most applicable method with which to portray the dynamic relations and outcomes involved in biofuel production and the transition to a green economy.

To generate and analyse simulations of social, economic and environmental scenarios, Bassi (2014) mentions that one has to consider data frameworks and modelling methodologies. While data frameworks generally deal with static information, modelling is based on dynamic factors. However, data frameworks often form the core of modelling approaches, based on the consideration that they are either used in isolation to obtain valuable information regarding the history and the current state of a system, or they are used as part of a simulation model in order to generate forecasts and predictions of key system indicators and variables. It is thus important to use dynamic methodologies to create a quantitative simulation model that would be able to engender future predictions. Some of these dynamic modelling methodologies include econometrics, optimisation and system dynamics, while the following data frameworks are generally used (Bassi, 2014):

- **Indicators** - Gives an indication of the current or historical state of a system and can prove useful in identifying trends and causal relations.
- **Input-Output frameworks (I-O)** - Highlights inter-industry relationships and sheds light on how the output of one sector becomes an input to a different sector.
- **Social Accounting Matrix (SAM)** - An accounting framework used to capture transactions in order to indicate the monetary flows between different

sectors.

- **Geographic Information Systems (GIS)** - A system designed to capture, analyse and present detailed geographical information.

The choice of dynamic methodology selected to analyse a system ultimately determines and constrains the static factors of the data framework that will be incorporated into the holistic dynamic model as well as the level of detail and information that will be available for analysis. Emphasis is thus placed on exploring and selecting the most applicable dynamic methodology or modelling technique.

2.5.1 Econometrics

Econometrics was originally developed for economic forecasts and guidance in the formation of governmental policies (Epstein, 2014). It entails the application of statistical methods to quantify and assess the hypothetical relationships between role players using the data available (Dougherty, 2011). Econometrics is a powerful modelling approach used to find correlations between variables, based on historical data available. It is based on sound statistical principles, which include probability theory, random statistical interference and regression analysis, amongst many others.

The building of econometric models consists of three stages which include specification, estimation and forecasting. Criticism exists regarding these steps, as the specification of equations to describe the relations and behaviour are based on estimations which often lead to inaccurate modelling (van Meerhaeghe, 2000; Bassi, 2014). There is some doubt regarding the possibility to identify the behaviour of equations when acting simultaneously and this makes it difficult to capture the full rationality of some elements in the model, while the availability of accurate data has always been another major limitation in econometrics (Epstein, 2014). Numerous techniques have been developed whereby econometrics can be used to predict future outcomes by simulating changes in exogenous input parameters that can then be used to calculate the variables that formulate the structure of the system. Some of the techniques used, rationalise data and variables resulting in the approaches neglecting the dynamic linkages amongst the variables and making it difficult to incorporate feedback effects into the model (Fennell, 2008).

Due to the high level of skills required to combine economic, statistical and mathematics principles, various software packages have been developed to simplify and strengthen econometric modelling. The software available includes STATA, R, GAUSS and MATLAB. Although these packages are very powerful, they are limited when less-common econometric methods have to be used, as the modeller will personally have to develop these programmes. Modellers also use a combination of the different software packages, as each package has its own distinct strengths and weaknesses (Hansen, 2015).

The main factors that result in econometrics being excluded as a feasible approach to explore the potential of a transition to green economy is, that the approach is fundamentally quantitative and forecasts produced are only a projection of the historical state (which is unavailable for the biofuel industry in the Western Cape Province). This modelling approach also makes it difficult to take future developments into account. Extensive mathematical and statistical knowledge is required to build strong and reliable models by means of econometrics, and even then it is limited by a relatively small system boundary, which will not give a holistic indication of the outcomes of biofuel production in the Western Cape Province.

2.5.2 Optimisation

Optimisation techniques are used to indicate the best possible way to achieve a certain outcome. Optimisation makes use of three inputs, where the first is having an objective or goal function, the second is the area of intervention and the last is the constraints that apply to the system. Using these parameters it is possible to build models that produce information on what the course of action should be in order to deliver the optimum outcome as defined by the goal function.

Large-scale optimisation models have achieved success in the past by making use of linear programming (LP), given the efficiency of the Simplex algorithm. The problem with modelling real world dynamic systems, by making use of LP is that real world problems contain resources and actors that can be difficult to break down in order to be represented by various goal functions and equations. Further challenges arise when attempting to establish the dynamic connections between these goal functions. LP is seen as a black box approach which limits the level of detail that can be provided by the solution (Turner *et al.*, 2002).

Many optimisation techniques exist (Integer Programming, Search Heuristics, artificial neural networks etc.) which exceed the capabilities of classic optimisation techniques and improve the amount of detail that can be provided. These techniques also deal with the shortcomings of LP. This has however proved to be a time consuming and costly way to obtain accurate optimisation results. Although impractically long computational times can be overcome by using certain approximation techniques, it is possible that these techniques will offer a non-optimal solution (Turner *et al.*, 2002; Banos *et al.*, 2011).

Optimisation is also used to evaluate the impact of external changes in a system, like in the case of Computable General Equilibrium (CGE) models. In CGE models, it is assumed that all agents will maximise individual welfare and optimisation mathematically delivers a solution that maximises the overall welfare of the system. However, the main purpose of CGE is policy analysis and is not well suited for forecasting (Bassi, 2014; Boulanger and Brechet, 2005).

The weakness of this approach lies in the fact that it can only accommodate very limited forms of feedback, which impinges its ability to act as a dynamic model. It can thus be said that an optimization model will not be a favoured method to predict the influences and outcomes of the potential of biofuel production, as optimisation models merely provide a snapshot in time of the ideal outcome, given certain initial assumptions and constraints. In support of this, Banos *et al.* (2011) describes optimisation to be highly efficient when dealing with situation specific cases like biomass energy production to determine the optimal energy distribution and describing the best strategy to use resources in a manner that will deliver maximized profit. Optimisation will however not be able to accurately capture the CAS of the Western Cape Province in its entirety.

2.5.3 System Dynamics

System dynamics uses a top-down approach and directly incorporates systems thinking to describe, model, simulate and analyse a CAS. It is based on the theory of systems structures and is both interdisciplinary and transdisciplinary (Kilham and Willetts, 2010). This means that it is well suited to incorporate most of the data frameworks mentioned earlier and incorporates indicators and I-O frameworks extremely well. System dynamics is used to represent complex systems and can analyse their dynamic behaviour over time (Wolstenholme, 2003).

System dynamics combines the principles and techniques involved in control and feedback systems with the structure of social, environmental and economic problems (Pruyt, 2013). A key strength of this modelling approach is that it makes use of feedback, stock and flow concepts, indicating that it is well adapted to accommodate complex systems that are both quantitative and qualitative in nature. The models are structured according to causal loop diagrams which indicate the complex interactions between the components of the data frameworks on an aggregate level.

A system dynamics approach sets out to understand what the main drivers for the behaviour of a system are (Bassi, 2014). It has been used extensively in policy testing and forecasting and is favoured for its ability to indicate consequences and outcomes of disruptions and deviations from the normal pattern or historical state. Like in the case where an aggregated system dynamic model of the worldwide food and bioenergy development was developed by Pruyt and De Sitter (2008) to indicate the interaction between food and bioenergy production. On a more detailed level, Musango *et al.* (2011) developed a model to explore the potential and possibilities of biodiesel production in the Eastern Cape Province of South Africa.

System dynamics is used to test and compare various scenarios to a predetermined baseline, which implies some shortcomings. These shortcomings include that causal loop diagrams and ultimately model variables and parameters are based on the modellers knowledge in identifying interconnections,variables, key indicators and possible changes or disruptions within the system. Functions and parameters of the model often require calibration and validation, which can be problematic due to the amount and quality of data required and available (Ouyang, 2014).

A major advantage of system dynamics is the fact that sub-models can be built and used interchangeably on more holistic models. Many of these sub-models have been validated in terms of their forecasting results and can be used with a high level of accuracy. System dynamics recognises that all problems are part of a larger system that is interconnected and that real world systems are not confined to disciplinary boundaries (Kilham and Willetts, 2010). The transdisciplinary nature of system dynamics thus makes it an attractive modelling approach for the real world modelling of biofuel production, as it can accurately describe a variety of outcomes for different scenarios and disruptions through complex interactions in various sectors.

2.5.4 Discrete Event Simulation

According to Cassandras and Lafortune (2008), a discrete event system is a discrete-state, event-driven system of which the evolution depends completely on the occurrence of uncoordinated discrete events over time. Discrete Event Simulation (DES) is based upon the foundation of the Monte Carlo methods and was originally developed for use in Operations Research, to improve the design and operation of manufacturing plants. It is a mathematical and logical representation of a physical system, which can undergo changes at predefined points in simulated time. The nature and time of changes require precise description for the model to be accurate (Albrecht, 2010).

The models are based on the concept of entities, resources and block charts describing resource sharing and flow processes. Brailsford *et al.* (2014) supports this by saying that DES represents the world as entities that flow through a network of queues and activities. Where entities are individual items that move through a system, queues are areas where entities are waiting to receive attention and an activity is work performed on an entity. The modelling process is driven by entities that are seen as passive objects, usually representing people, parts, tasks, messages or resources, while they travel through blocks of the flowchart where they are processed, delayed, combined or split (Borshchev and Filippov, 2004).

As the name suggests DES was invented to simulate event-driven systems and classic examples of DES include simulating customers waiting for service, cars waiting at a traffic light or the management of inventory. DES has been used extensively in analysing and modelling the following real world situations: queueing systems, computer systems, communication systems, software systems and hybrid systems, which is a combination of event- and time-driven dynamics (Cassandras and Lafortune, 2008).

DES is a powerful simulation technique, in that it can model stochastic (by making use of pseudo-random number generation) and deterministic events. In order to achieve more accurate predictions, DES has also been used in conjunction with optimisation techniques with great success (Riley, 2013). Some specialist software packages include Arena, Simio and SIMUL8.

The drawback of this modelling technique, making it less suitable for biofuel production modelling, lies in the emphasis the technique places on rigid sequencing of events, while tending to focus less on the dynamic processes involved in any system (Sumari *et al.*, 2013). Although DES can offer a more detailed simulation of the system behaviour over time by making use of very small time steps, this causes impractically long computation times. This is further complicated by the stochastic nature of DES, which causes variation in the proposed solution, requiring a simulation to be repeated numerous times in order to reach an accurate converging optimum solution and a better understanding of the output distribution (Brailsford *et al.*, 2014).

2.5.5 Agent Based Modelling

Agent Based Modelling (ABM), in contrast to system dynamics, uses a bottom-up approach based on agent level interaction. It is a form of microsimulation where the behaviour of individual decision makers are modelled within a larger system. Data is normally collected on samples and incorporated into decision rules, algorithms and equations, that stipulate the behavioural rules which individuals in the system will follow (Helbing and Balietti, 2013). ABM is exceptionally powerful in the case where a system has a high level of complexity and non-linear interactions which are not governed by a system-wide set of rules. When viewing a system on agent level, four key assumptions are made (Macy and Willer, 2002):

i. The system is not explicitly modelled as a holistically integrated entity;

ii. Agents are interdependent of their surroundings and other agents;

iii. Agents follow a set of simple rules (indicating that the complexities actually result as a reaction to the complexity of the environment in which agents find themselves); and

iv. Agents can adapt at an individual or population level and will thus form a CAS.

From these assumptions, it should be noted that ABM can be utilised to obtain global behaviour of a complex system, even when very little is known on how factors influence one another or the global sequence of operations. Bonabeau (2002) supports this by stating that the main benefit of ABM lies in its ability to capture emergent phenomena. The emergent phenomena results from the interaction of individual agents, and simulation results obtained are more than the sum of the individual entities. It is thus necessary to know the rules that govern the behaviour of individual entities. ABM is also favoured by many modellers for the natural representation of the system (Bonabeau, 2002). For example, it would be easier to describe how people move in a shopping mall than finding/formulating the equations that describe the dynamics influencing their behaviour, like density of people and obstructions, etc.

ABM can be used in conjunction with other modelling techniques (making use of discrete or continuous fields), leading to extensive simulation capabilities like in the cases of weather, environmental and climate simulations (Helbing and Balietti, 2013). Although ABM is intended to go well beyond the abilities of system dynamics, it is generally more challenging to develop useful models because it requires extensive knowledge regarding the behaviour of individual actors. The fact that it is actor based also means that the system is analysed on constituent level and large systems are thus very computation intensive (Bonabeau, 2002).

ABM is mostly used to model situations where agents are not in fixed positions, but the space in which they move is crucial. There are some complications when using ABM to assess social, political and economic situations, as soft factors are difficult to quantify and justify (Bonabeau, 2002). ABM is thus recommended when the system cannot be accurately modelled by using system dynamics or DES (Borshchev and Filippov, 2004). Although ABM is an exceptionally powerful simulation technique, it will not be the best approach to model biofuel production in the Western Cape Province due to the extent of the system boundary and the number of different disciplines involved. The process to gather/generate the relevant information and build the model will be resource intensive and time consuming, while the results could still be comparable to that of a system dynamic model.

2.5.6 Network Models

Boccaletti *et al.* (2006) explains that although network modelling was initially concerned with discrete mathematics (more commonly known as graph theory), the methodology has evolved drastically to include dynamic network analysis. Most fields have developed principles that adapt networking models for a specific purpose, like the development of Social Networking Models in the social sciences. There has been an increasing interest in the investigation of complex networks, where Boccaletti *et al.* (2006) describes a complex network to be one that has a complex and irregular structure that is evolving over time. There is also a much larger amount of nodes involved in complex networks (where nodes in the millions have been used before).

Network models are mainly used to indicate the correlation or the relationships between different entities or agents. Entities, logic rules and constraints are user defined and usually based on physical behaviour, past experience or data available. Nodes are used to present entities. The model will then follow the logic rules stipulated for each node (node behaviour) and satisfy the constraints in order to produce the optimum sequence of events or calculating the structural properties of certain nodes, groups or the complete network. Network analysis further enables the prediction of the creation, growth and dissolution of networks and can facilitate in the investigation of the effects of networks on the behaviour of actors (Hafner-Burton *et al.*, 2009).

Complex network models give insight into how interacting dynamic systems behave collectively (based on their individual nature and coupling architecture) and have been used successfully in most sectors, including food webs, neuron transmissions, power stations and the internet (Strogatz, 2001). Networking modelling is an extremely vast and diverse field, but some of the more common examples of network modelling include uses in the minimum cost flow problems, shortest path problems, assignment problems and various types of network optimisation problems (Bertsekas and Scientific, 1998).

Figure 2.3 shows an example of how the network modelling was used to determine whether human genetic disorders and corresponding disease genes are related at a higher cellular and organismal level (Goh *et al.*, 2007). The network model was initially populated with 1284 disorders and found that only 867 of these were related to at least one other disorder. The legend on the right indicates the disorders that emerged with the highest number of diseases in common. This shows how network modelling can be used to identify the complex interrelatedness of entities that would at first glance seem chaotic and unrelated.

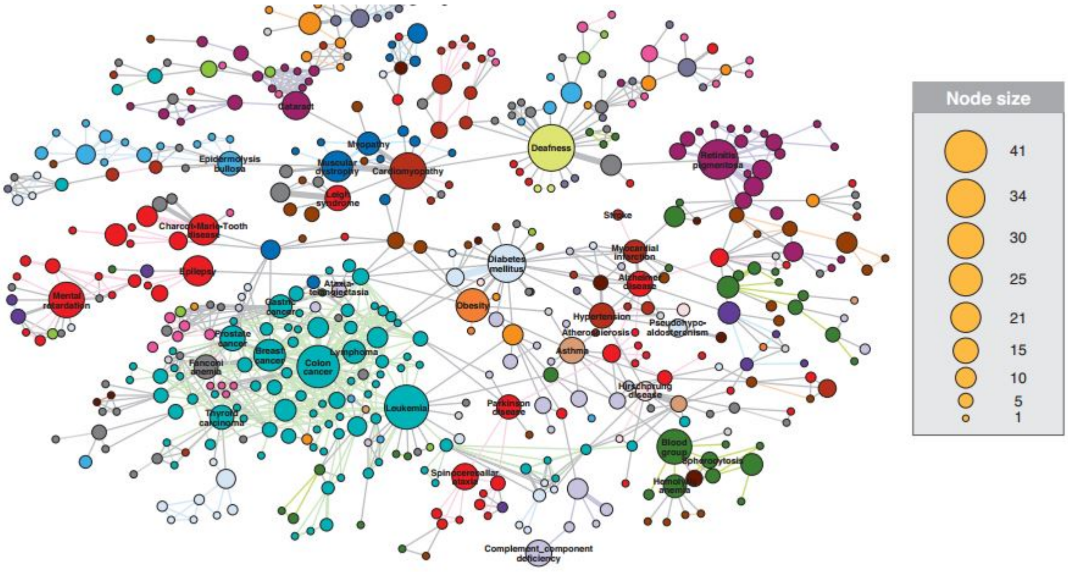

Figure 2.3: Human Disease Network (Goh *et al.*, 2007)

Although network models are generally used to describe qualitative connections between entities, they have limited capability to receive, manipulate and produce quantitative values or parameters, where numerical values are assigned to causal effects on stocks and flows, like in the case system dynamic models. Network models are also actor-based and tend to focus on simulation of a single theory or entity, and have difficulty incorporating entities across various dimensions into a single model (Snijders *et al.*, 2010; Le Novère, 2015).

Network modelling is not a feasible approach for modelling biofuel production, as it has restricted quantitative abilities and difficulty in projecting change or behaviour over time.

A comparison of the various modelling techniques reviewed and discussed is necessary in order to conclude on the most appropriate technique to be used for the evaluation and simulation of biofuel production.

2.6 Modelling Technique Assessment

It is evident from the literature above that a variety of modelling methods are available to simulate and guide outcomes of complex systems. Table 2.2 summarises these at the hand of selected key characteristics that were deemed essential to accurately model the implications of a green economy transition.

These factors were used to select the most appropriate modelling methodology, based on common problems experienced by other modellers within each discipline as well as an analyses of the modelling work done by Bassi (2014) and Karnon (2003). The table indicates the main strength and weakness of each modelling technique and determines its ability to meet the following qualifying factors:

1. **Problem identification** - Does the modelling technique assist the modeller in identifying the actors and various role players within the system?
2. **Flexibility** - Does the model adapt well to different input data and changes interrelationships?
3. **Outcome Accuracy** - Do the results of the model justify the computational intensity?
4. **Indication of effect over time** - Does the model provide the expected outcome of the system over a time period specified in order to model future predictions?

Bassi (2014) discussed how combinations of different static and dynamic methodologies can be used to assess different dimensions relevant to a green economy. He ultimately states that system dynamics can represent economic, social and natural capital, but the level of detail given by the model will depend on the identification and understanding of the key drivers and the availability of accurate data. Indicators are identified to be the most appropriate data framework methodology to assess green economy processes, at the hand of the contribution to the policy process and the stakeholder participation. It is thus concluded that system dynamics used in combination with indicators will be the best approach to determine the effects and outcomes of biofuel production in the Western Cape Province.

Table 2.2: Modelling Methodologies

Methodology	Main Strength	Main Weakness	Problem Identification	Flexibility	Outcome Accuracy	Indication of effect over time
Econometrics	Based on historical trends	Absence of feedback effect	✓			✓
Optimisation	Gives an accurate estimation of whether a target can be reached (given set constraints)	Does not identify the drivers contributing toward reaching target			✓	
System Dynamics	Simulation driven by root causes and effect (accurately capturing dynamics and feedback effects)	Input parameters need to be obtained from experts across all sectors	✓	✓	✓	✓
Discrete Event Simulation	Simulating (random or ordered) event-driven systems, where entities have to take part in processes	Rigid sequencing of events and stochastic nature produces varying solutions (time-consuming to run various simulations)				✓
Agent Based Modelling	Captures Emergent Phenomena (by working on agent level)	Computation intensive and limited capability to integrate actors from different sectors on the same platform	✓	✓		✓
Network Modelling	Identifies the most important actors in a seemingly chaotic complex system and shows connections between entities that would otherwise not be easily identifiable	Limited ability to receive, manipulate and produce quantitative values or parameters	✓	✓		

Chapter 3

Modelling Approach

The following chapter provides some background on the model parameters and the modelling approach. The chapter continues to indicate how a systems thinking approach to biofuel production is ultimately incorporated and captured in the form of a system dynamic model. The details of the system dynamic model is discussed within the chosen systems thinking and modelling framework.

3.1 Modelling Framework

When using system dynamics as part of a systems thinking approach to capture and describe the complexity of a system, various frameworks are proposed. Some of these frameworks were developed during the infancy of system dynamics. The proposed frameworks have not seen any real fundamental changes. Table 3.1 compares some of the frameworks proposed by various authors and it can be seen that the same fundamental elements are present in all of these approaches.

Luna-Reyes and Andersen (2003) mention that the modelling process is divided into different phases by each author, while the activities considered as part of the modelling process remain fairly constant. Evaluating the different approaches on a more detailed level shows that although the activities are categorised and named differently, all of the authors suggest a similar approach. The common steps present in all of the proposed modelling frameworks show that a conceptual qualitative phase is first necessary to define the problem structure and area. Subsequently an iterative process, which tests a dynamic hypothesis (representing the causal nature), is used to simulate behaviour over time under different circumstances. This allows one to learn about the process and test or design certain guidance policies.

Table 3.1: System Dynamics modelling process (Adapted from: Luna-Reyes and Andersen (2003))

Authors	**Randers (1980)**	**Wolstenholme (1990)**	**Sterman (2000)**	**Maani and Cavana (2007)**
Modelling Phases	Conceptualisation	Diagram construction and analysis Dynamic Hypothesis	Problem Articulation Causal Loop Modelling	Problem Structuring
	Formulation	Simulation (Stage 1)	Formulation Scenario Planning and Modelling	Dynamic Modelling
	Testing	Simulation (Stage 1)	Testing	Scenario Planning and Modelling
	Implementation	Simulation (Stage 2)	Policy formation and evaluation	Implementation

Even though general consensus is reached across all of the frameworks that are reviewed, for the purpose of this study, the framework proposed by Maani and Cavana (2007) is followed. This framework was selected for its detailed and versatile approach. The framework provides extensive and elaborate step by step guidelines in order to improve model transparency and repeatability. It is also one of the more recent frameworks.

According to Maani and Cavana (2007), the development of a systems thinking and modelling approach consists of five phases (earlier indicated in Figure 2.2). Within each phase, certain steps are recommended to assist in the development of a holistic and reliable model. Cavana and Maani (2000) mention that not all five of these major phases nor the full process within each phase have to be undertaken, but that these phases are a guideline to be followed, depending on the level of intervention possible and nature of the specific issues at hand, along with the effort available to overcome them.

3.2 Problem Structuring

The events that lead up to the need for biofuel[1] production within the Western Cape Province are detailed in Section 2.2. The following section contains the problem structuring on a more technical level and identifies the problem area under consideration, as well as the policy concerns involved. Preliminary technical information, parameters and the boundary of the problem area are also discussed.

3.2.1 Problem Context

In order to facilitate the transition to a green economy by reducing GHG emissions, creating employment and strengthening the economy, the WCG aims to promote clean energy as part of the *"Green is Smart"* framework. The framework also coincides with the with National Biofuels Industrial Strategy, which mandates the blending of the national fuel pool with a minimum of 2% bioethanol and 5% biodiesel with petroleum based petrol and diesel respectively. The mandatory blending policy is stated to be effective from October 2015. The biofuels strategy further stipulates incentives and subsidies for biofuel producers in order to attract sustainable investment. This includes paying a subsidy to producers per litre of biofuel **blended** to ensure a guaranteed Return On Assets (ROA) of 15%, comparing to a benchmark[2] plant, where the framework defines ROA as in Equation 3.2.1. Calculations based on initially proposed reference plants indicate a subsidy of up to R1.95 and R2.53 per litre of bioethanol and biodiesel, respectively. The latest draft framework further stipulates a 50% general fuel levy exemption to biodiesel producers. A similar incentive could not be achieved for bioethanol production as it falls outside the tax net (Department of Energy, 2014).

$$ROA = \frac{Earnings\ before\ interest\ and\ taxes}{Total\ assets} \tag{3.2.1}$$

In response to the mandatory blending policy, various national and international corporations have investigated the possibility of producing biofuel in SA. The Western Cape Province accounts for roughly 15% of the country's total fuel demand, but does not have any proposed biofuel production facilities to date. The Province could be a vital counterpart to assist in displacing the stated fossil fuels,

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[1] It is important to note that biofuel serves as a collective name and in this study refers to both bioethanol and biodiesel. A similar approach is thus followed to evaluate the effects and impact of the blending policy for both biofuels.

[2] The draft framework defines major assumptions (like the use of Sorghum and Soya Beans as reference crops) made to constitute a reference or benchmark plant. Although various concerns have been raised with regards to these assumptions, the final structure is yet to be announced.

due to the unique winter crop growth and the strategic location of depots and refineries within the Province. The depots and refineries are operated and owned by independent companies, which are obliged by the blending policy to accept biofuel (provided they meet the stipulated requirements) for blending purposes. The physical blending process could happen at refinery or depot level, although it is recommended that blending happens at a depot level due to constraints and costs involved in refinery blending (Department of Energy, 2014).

Figure 3.1 shows the location of the country's network of fuel depots, as well as the biofuel production sites proposed by companies that have already applied for a license to produce biofuel (Appendix B contains the detailed list of projects and their status). Figure 3.1 indicates the proposed biofuel plants are all situated to the east of the country, implying that if the Western Cape Province is to form part of the biofuel blending scheme, biofuel will have to be transported long distances by road (causing more GHG emissions and placing additional pressure on infrastructure). Noting that these increased emissions will counteract one of the driving factors (emission reduction) for biofuel production in the first place and the fact that none of the proposed biofuel plants are operational yet, the feasibility and effects of local production to supply and blend biofuel in the Western Cape Province should be investigated.

In order to investigate the feasibility of diversifying the Province's fuel supply mix by having the stipulated biofuel blended into the fossil fuels, the various effects and implications should be evaluated. Previous studies have investigated biofuel production in the Western Cape Province and the most feasible options in terms of production techniques, feedstock crops, production capacities, etc. have been identified. In evaluating the impact and the role of the Western Cape Province in the blending policy, the following areas are of key concern:

i. biofuel production plant;
ii. agriculture;
iii. food security;
iv. land issues;
v. water resources;
vi. energy requirements;
vii. by-products; and
viii. biofuel sales price.

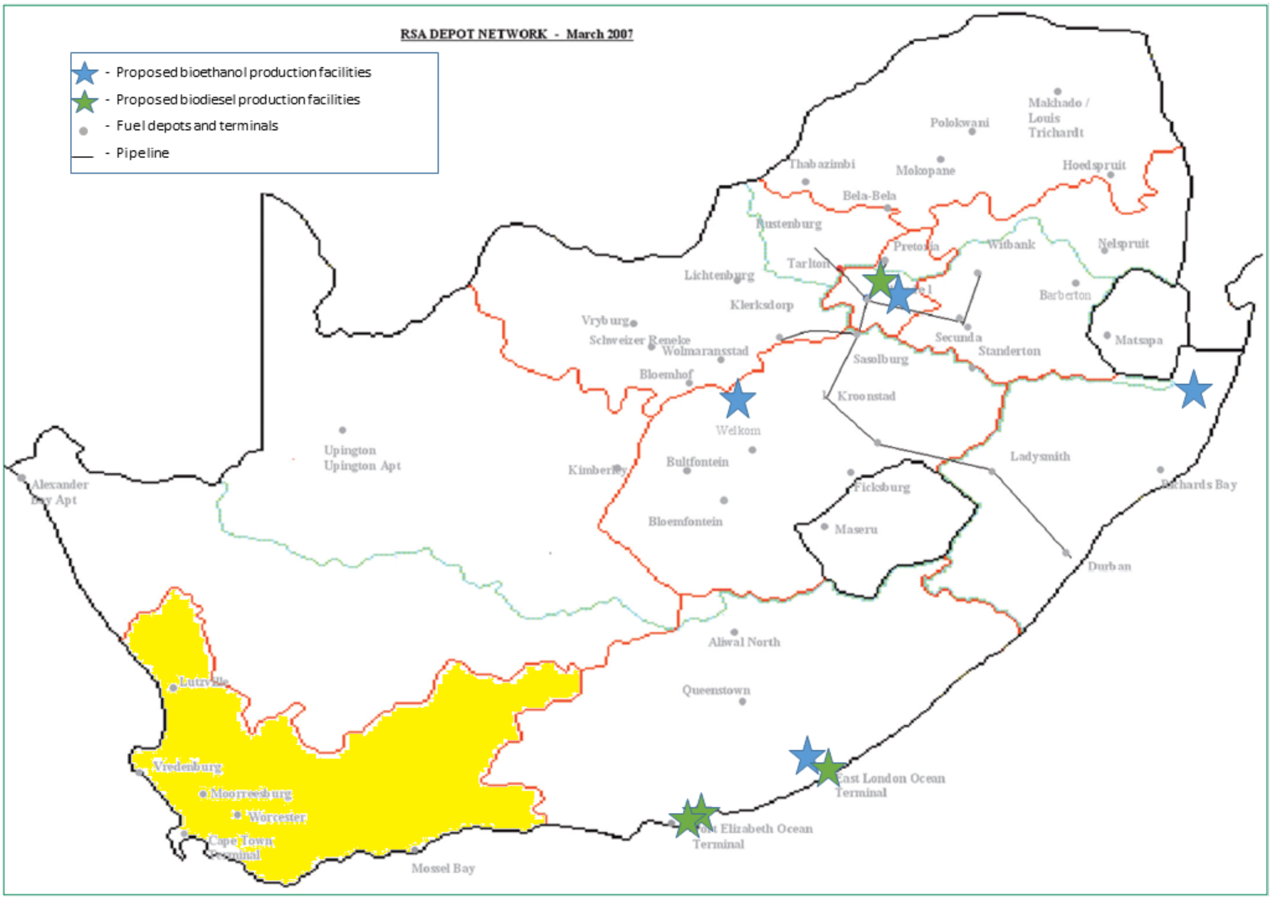

Figure 3.1: RSA - Fuel depots and planned biofuel facilities (Adapted from: South African Petroleum Industry Association (2008))

Different methods are used to produce biofuel and a variety of technologies are available in **biofuel production plants**. Bioethanol can be produced by a dry-milling or wet-milling process. Figure 3.2 depicts a typical dry-mill production facility, and shows the inputs and outputs of the production process. The dry-mill process involves grinding the feedstock into a powder before the process is started, while the wet process sees the feedstock kernel broken down and separated into its component parts before fermentation. Dry-milling is more commonly used for commercial bioethanol production and the specific approach followed can also differ in terms of different operating temperatures and bran removal processes, etc.

The biodiesel production process is less complex than that of bioethanol. It starts with oil extraction from the feedcrops, going on to optional pre-treatment, followed by transesterfication (whereby glycerine is removed from triglyceride) and lastly the glycerine and biodiesel are separated and purified. Biofuels can be produced in a batch or continuous process. The production process used and the production capacity of the facility will thus be the main determining factors for the local production scenario. The type and size of the plant constructed will influence the operational expenditure (OPEX) and capital expenditure (CAPEX) required, as well as the amount of feedstock end energy needed.

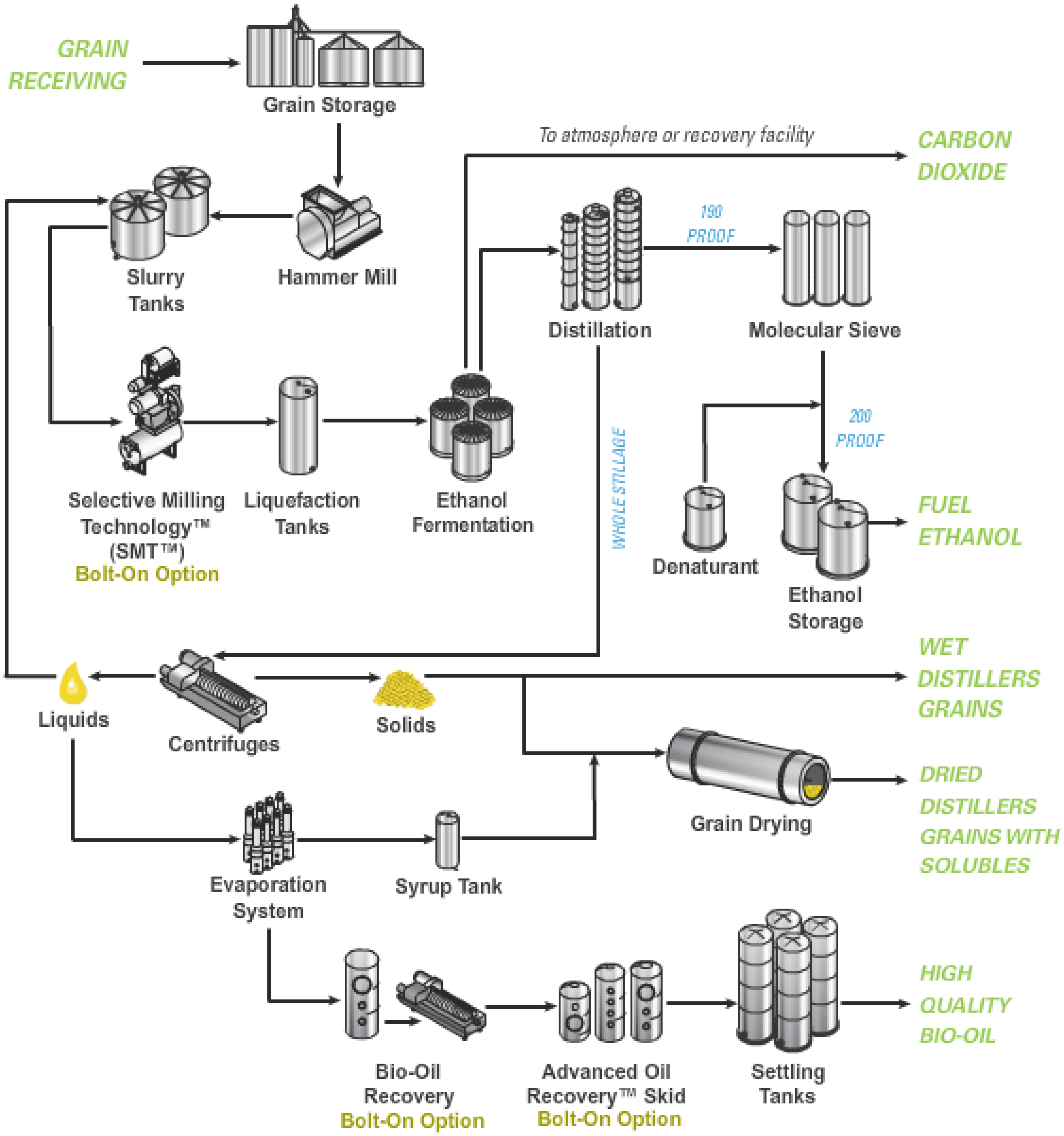

Figure 3.2: Dry-mill bioethanol production facility (ICM Incorporated, 2015)

The **agriculture** sector is a key driver to biofuel production. In the Western Cape Province, small grains like barley, wheat and canola are farmed extensively and are considered viable feedstock crops for biofuel production. Amigun *et al.* (2011) identified the most feasible feedstock crop for bioethanol production to be triticale[3], due to its ability to grow in marginal soil and the relatively high yield factor. Large scale biodiesel production in the Western Cape Province has been deemed less lucrative due to the high costs of waste vegetable oil and canola. The market value of waste vegetable oil is comparable to that of biodiesel per litre, and has thus excluded it as a viable feedstock. **Food security** is directly related to the agricultural production and because canola is used in food production, it can only be used for biofuel production in limited quantities to ensure that biofuel production does not influence food security in a negative way.

The Western Cape Province has a total **land area** of roughly 12.9 million hectares, of which about 19% is suitable for growing crops (Vink and Tregurtha, 2005). The biofuel strategy stipulates that biofuel feedstock may only be sourced from designated areas, where a designated area is defined by the Department of Agriculture as an area that is underutilised and suitable for biofuel feedstock crops. It is uncertain how *"underutilised"* land will be classified, but the strategy aims to encourage the sourcing of biofuel feedstock crops from emerging farmers. Underutilised areas can be seen as marginal to low potential land, which makes up a large portion of the Province's land (Department of Environmental Affairs and Tourism, 2006). The amount of land required for biofuel production is determined by the agricultural crop yield (per hectare) and the biofuel yield per feedstock weight.

Producing biofuel will place additional stress on **water resources**. Bioethanol production specifically requires large quantities of process water, make up steam and cooling water. In many commercial biofuel facilities, the most water intensive aspect is growing the feedcrops. It is however unlikely that this will be the case for the Western Cape Province, as the small grains agricultural sector relies mainly on the winter rainfall and does not make use of extensive irrigation. Water use will thus mainly be determined by the initial requirement for process water, the make up water lost in the process and the water used in production that forms part of the ultimate amount of biofuel produced.

As with any other industrial process, it is expected that biofuel production will have large **energy requirements**. Referring to the process described in Figure 3.2, bioethanol production will require process heat, where process heat is normally supplied by an independent boiler system operating on gas, coal or biomass

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[3] Triticale is a hybrid between wheat and rye currently used as animal feed.

as combustibles. Electricity is also required to operate the various machinery and pumps in the process. Electricity is generally supplied by the national electricity utility provider (Eskom), although independent electricity generation is becoming increasingly popular due to the national energy crisis[4] and continued price increases[5]. Biodiesel is generally considered less energy intensive than bioethanol production due to the relatively elementary production process followed.

As part of a holistic view on biofuel production, one would have to consider the **by-products** produced by the process. The process of bioethanol production delivers Dried Distillers Grains and Soluables (DDGS) as a by-product. DDGS is used as a nutrient rich animal feed and could be of vital importance to the South African livestock sector, as SA is a net importer of protein based animal feeds. Biodiesel production delivers glycerol (known as glycerine) and oilcake as by-products. Glycerine is used in the food, pharmaceutical and cosmetic industries, while oilcake is also used as animal feed. SA imports 63% (over a million tons) of its oilcake annually, indicating that a substantial market exists for animal feed. The large increase in biodiesel production capacity on a global scale has lead to a saturated market for glycerine. Coupled with the high cost of purifying the glycerol produced as a raw by-product, it is unlikely that glycerine will positively contribute to the biofuel value stream in the Western Cape Province.

Some uncertainty exists regarding the overall environmental impact of biofuel production, as carbon dioxide is released as a by-product and increased agricultural activity leads to increased carbon emissions. The entire life-cycle has to be considered when evaluating the net carbon emissions of biofuel production, as the increased agricultural activity can also lead to increased carbon sequestration. The overall effects of displaced fossil fuels can also be difficult to quantify. The Kyoto protocol stipulated a mechanism in which organisations are rewarded financially for displacing carbon units in the form of a carbon trading scheme (United Nations Framework Convention on Climate Change, 2015). Although the cap-and-trade system has been successfully implemented in other countries, there exists some uncertainty regarding their effectiveness and the carbon market in SA has not yet been established. The contribution of a carbon sales as part of the business case of biofuel production in the Western Cape Province is thus excluded.

Ultimately the financial feasibility of biofuel production depends on the income

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[4] SA is experiencing a power shortage and has seen the implementation or controlled rolling blackouts since 2008.

[5] The national energy regulator (NERSA) approved a 12.7% price increase for 2015/2016 and Eskom is applying for further increases, which could result in a total electricity tarrif increase of 25% in one year.

generated from biofuel sales. Various pricing structures are used to determine the **biofuel sales price**. From Appendix A, it should be noted that biofuels have reduced energy densities when compared to fossil fuels, which influences the market value of biofuel. The fossil fuel price in SA is determined by the basic fuel price (BFP), which is largely determined by the price of crude oil and the exchange rate. The biofuel pricing structures are thus normally based on the BFP and take the volumetric energy density of the respective fuels into consideration.

At the hand of these key areas that drive and constrain biofuel production, a model that considers the interaction between all of these areas will provide insights into biofuel production in the Western Cape Province. The bottom line cost or financial implications of complying with the blending mandate, as well as emissions comparison and the subsidy required for various scenarios are some of the major concerns of the simulation.

3.2.2 Model Boundary

In order to assess the implications of the blending mandate for the Western Cape Province, the model assumes and simulates the Western Cape Province as a country in its own right and does not take resources shared on national level into account. The model does not aim to simulate effect of possible spin-off industries. It is assumed that legislative and other qualifying criteria as stipulated in the PPA act and Biofuels Industrial Strategy are met and the model only aims to indicate effects on the key areas previously identified.

The biofuel production model makes up part of a larger model[6] that aims to indicate the *"Western Cape's Transition to Green Economy"*. The time horizon for the biofuel model is thus the same as the larger model and runs from 2001 - 2040. This was done because the 2001 census in SA provided accurate data for model validation and helps to improve model accuracy.

With the time frame of the blending mandate in mind and the estimated construction time of a biofuel plant to be between one and a half and four years, it is assumed that the biofuel facilities in the Western Cape Province are constructed and operational by the end of 2018. The adverse effects of biofuel production and implications of forming part of the blending mandate are thus indicated until 2040, which should provide a holistic picture as the normally expected life of a biofuel plant is taken as 20 years.

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[6] The WeCaGEM model was presented at the 33rd International Conference of the System Dynamics Society held in 2015 at, Cambridge, Massachusetts, USA (Musango *et al.*, 2015).

3.2.3 Preliminary Information and Data

Establishing the structure of biofuel as a complex interrelated system required an investigation into the main drivers and policies at work within the system. Some preliminary data and information was gathered in order to have a better understanding of the parameters influencing biofuel production in the Western Cape Province specifically. Numerous studies have looked at establishing biofuel production plants in the Western Cape Province, and although not all the findings were consistent due to different assumptions made, the information is valuable for investigating the overall effects of biofuel production. All policy and legislative parameters are gathered from the Biofuels Industrial Strategy of the Republic of South Africa (Department of Minerals and Energy, 2007) and the draft Position paper on the South African Regulatory framework (Department of Energy, 2014).

3.2.3.1 Bioethanol

The Western Cape Province's unique geographic and climatic properties have lead to numerous studies and technology assessments. Feedstock costs typically constitute between 60-70% of the operational costs and feedstock selection also determines the type of process to be used and the by-products that will ultimately be produced. Lemmer (2006) identified starch-to-ethanol plants to be the most appropriate for the Western Cape Province and analysed the business case for ethanol production making use of wheat. Amigun *et al.* (2012) proposed the use of triticale in bioethanol production, as it has a higher ethanol yield per feedstock volume (470 litres/ton) when compared to wheat (450 litres/ton) and barley (400 litres/ton). Triticale is also favoured for its ability to grow in marginal soil.

A technology assessment was completed by du Preez (2015), where the warm and cold grinding process was compared to the pre-fractionation dry grinding production process. The study indicated that pre-fractionation[7] with dry grinding would be the most economically viable process.

The proposed size of the production plant is 160 million litres per annum which is the same as that of the reference plant used in the biofuel strategy. Operating at full capacity, it is expected that roughly 370 000 tons of triticale is required. Over and above the feedstock, the other inputs required are enzymes, yeast, water and energy, while the outputs of the production process will be bioethanol and DDGS (du Preez, 2015).

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[7] Pre-fractionation is similar to the conventional dry grinding process, but has some economic benefits due to the bran being separated from the triticale grain before the final fermentation is started, resulting in smaller equipment requirements and a much higher quality DDGS.

Taking all of the operational costs, capital costs and revenue streams into account, it is possible to calculate the required subsidy per litre of biofuel produced by using Equation 3.2.1 and ensuring that a ROA of 15% is achieved. Table 3.2 shows some preliminary parameters for biofuel production that were used in previous studies. This study uses the latest parameters as indicated by the relevant parties like: Green Cape (2015), du Preez (2015), The Department of Minerals and Energy and Eskom.

Table 3.2: Preliminary data on bioethanol production

	unit	**Amigun *et al.* (2012)**
Feedstock	-	Wheat, Barley, Triticale
CAPEX[a]	R ' 000 000	383-782
OPEX		
electricity cost	R/kWh	0.19
feedstock cost	R/ton	3450
DDGS price	R/ton	2500
water cost	R/kL	6.58
Interest rate on capital	%	14.1%
Expected ROA	%	25%
Ethanol selling price	% of BFP	66%

[a] CAPEX differs substantially depending on the feedstock and production technique used (prices indicated are for a plant that can process 200 000 tons of feedstock per annum).

3.2.3.2 Biodiesel

It has been mentioned that biodiesel production in the Western Cape Province has proved to be infeasible due to low availability of feedstock and the high price of these feedstocks. The simulation however looks at reassessing the biodiesel production scenario at the hand of the latest pricing mechanisms. Canola was identified as the feedstock to be used, and it is estimated that 25% of the region's canola production can be diverted to biodiesel production without affecting food security. Canola yields about 454 litres of biodiesel per ton, and there is a market for an estimated 70 million litres per year, which will require 220 000 tons of canola. This is six times the total canola production seen in 2010 and shows that only a small to medium scale facility of 25-40 million litres per year could be feasible (Department of Agriculture, Forestry and Fisheries, 2012; Green Cape, 2015).

When using canola as feedstock, a seed extraction biodiesel production plant is used, which is similar to a crude oil processing plant, but with the added step of extracting the oil from the crops. Inputs used in the processing plant are feedstock, energy, water, and chemicals. The chemicals used are methanol and a catalyst (Potassium Hydroxide is commonly used.) The outputs of the biodiesel refinery process are biodiesel, glycerine, methanol, other chemicals and crop residues. The methanol can be reused in the process, but this is generally not done, due to quality concerns (Nolte, 2007).

Table 3.3 shows the preliminary information that was used by previous assessments. The current study uses information from Nolte (2007), Green Cape (2015), Fore *et al.* (2011), the Department of Agriculture and Eskom.

Table 3.3: Preliminary data on biodiesel production

	unit	**Nolte (2007)**
Feedstock	-	Canola
CAPEX[a]	R ' 000 000	110
OPEX		
electricity[b]	R/kWh	-
feedstock	R/ton	1900
Oil Cake price	R/ton	1830
Water price	R/kL	2.88
Methanol	R/ton	3450
Potassium Hydroxide	R/ton	7800
Expected ROA	%	10%
Ethanol selling price	% of BFP	95%

[a] Price indicated for a plant that can produce 22.5 million litres of biodiesel per annum.

[b] The assumption was made that electricity will be generated by an on-site generator, powered by the biodiesel produced.

3.3 Causal Loop Modelling

In order to build a model that can holistically combine all of the information and drivers identified, the biofuel production sector is first approached conceptually. Forrester (1994) warns against the use of causal loop diagrams as the beginning point for model conceptualisation, as it does not identify level variables responsible for the dynamic behaviour present in a system. Instead he recommends starting by identifying the system levels and later developing the flow rates influencing the system levels. During the conceptual phase, main variables and indicators are identified, expected behaviour analysed (by showing the relationship between drivers) and key leverage and intervention points are identified.

3.3.1 Identification of Main Variables

Various documents were investigated and industry professionals were consulted to assist in identification of the main variables that constrain and drive biofuel production in SA and the Western Cape Province. The key variables that are ultimately used as the indicators for biofuel production are categorised according to the three pillars of sustainability, where the description and dimension of each variable is shown in Table 3.4. These indicators were identified by taking both financial feasibility (from a project developer perspective) and adverse effects (from a policy and decision maker perspective) into account. An indicator like employment is thus shown as a positive adverse effect to policy makers, while the financial impact to project developers is also shown.

Each one of the main variables can be divided into the different factors that drive and affect the variables. The table illustrates that although many complex interactions between variables are present in the system, the overall effect of biofuel production can be measured in terms of the change in a few key indicators.

The key indicators of the **environmental** sector, include emissions, resources used and by-products produced, as these indicators will be used to determine whether the production of biofuel benefits the environment.

The only major **social** aspect affected by biofuel production is the creation of additional employment to improve the general living quality of people in the Province. Employment creation is further likely to lead to improved public perception of the use and production of biofuels.

The **economic** factors that can establish the feasibility of biofuel production are the investment required into biofuel (considering CAPEX and OPEX), as well as the overall profitability and the subsidy required for biofuel production. The bottom line cost ultimately determines whether it is better to buy in biofuels from existing plants or to produce biofuel locally within the Western Cape Province.

Table 3.4: Model indicators

	Indicator	Description	Units
Environment	Emissions	Change in air emissions due to investment into biofuel & biofuel electricity demand	kg CO_2 / year
	Land use	Additional agricultural land required due to biofuel feedstock growth	Ha
	Water use	Additional water required due to biofuel feedstock growth & production	litre/year
	Electricity use	Energy used to produce biofuel	kW
	Biofuel by-product	Amount of DDGS produced per year	litre/year
Social	Employment	Additional employment creation due to biofuel production	Person
Economic	Investment into biofuel	Capital investment needed to produce biofuel	Rand
	Operational Cost	The running cost of a production facility to produce biofuel	Rand/year
	Subsidy required	The subsidy required per litre to attain a 15% Return on Assets (ROA)	Rand/litre
	Internal Rate of Return (IRR)	Profitability of investing into biofuel production	%
	Bottom line	The overall bottom line cost implications of providing biofuel to the Western Cape consumer through local production or inter-provincial imports	Rand

3.3.2 Causal Loop Diagram

CLDs are used to indicate the nature and direction of relationships within the system. They also assist the modeller to better understand the system and its interactions. CLDs are also used to visually present feedback existing in the system. Feedback can be either balancing (B) or reinforcing (R), where balancing feedback tends to seek stability or converges to a certain goal function. Reinforcing loops on the other hand have positive feedback and will cause a continued growth or decline, unless an external factor intervenes. This can be better explained at the hand of an example by referring to loop R1 and B1 in Figure 3.3.

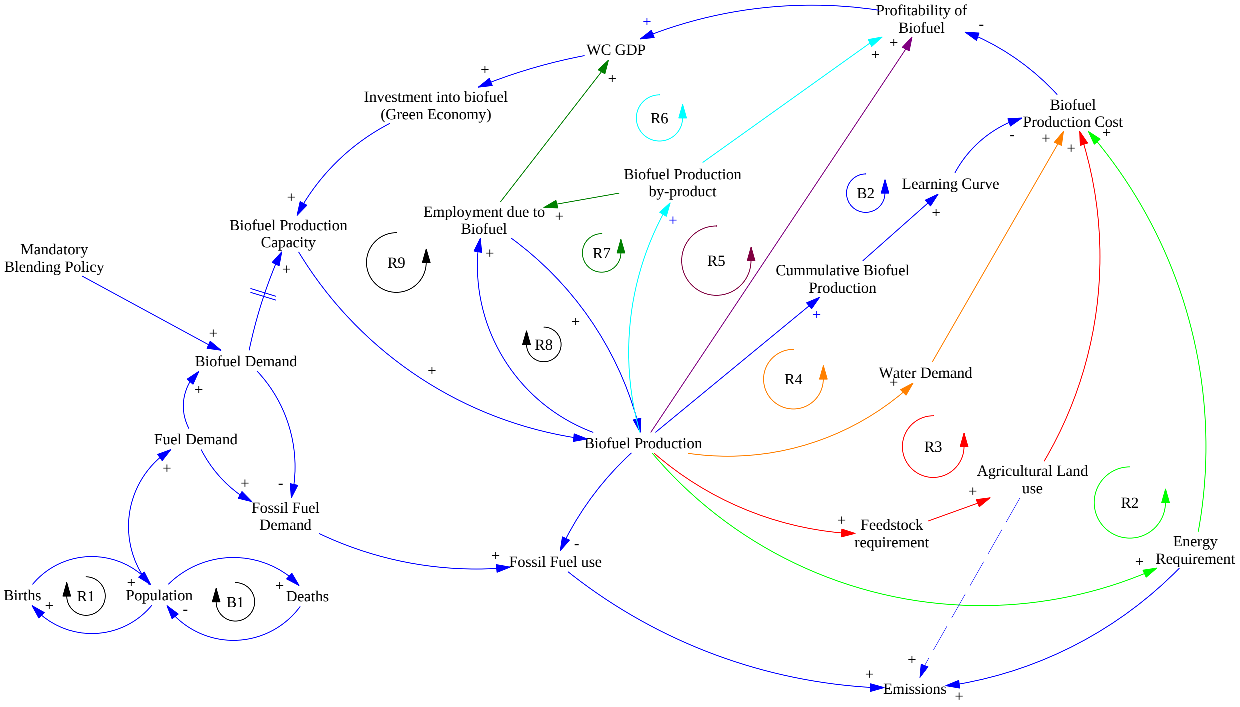

Figure 3.3: Causal Loop Diagram

R1, shows how an increase in the population causes more births (+) and an increase in births again causes growth (+) in the population. The two positive causalities show that this feedback loop is reinforcing as it will continue to grow if no other factor influences it.

B1 is the balancing loop that will tend to stabilise the system, and this can be seen in how an increase in population will increase (+) the number of deaths witnessed, but an increase in deaths will decrease (−) the population.

The CLD further shows a causality between the population and fuel demand, as an increase in the population will lead to increased fuel demand (+). The mandatory blending policy as an exogenous factor will then increase (+) the biofuel demand (based on the total fuel demand) and an increase in biofuel demand will decrease the fossil fuel demand (−) while influencing fossil fuel use in the same direction (+) to decrease it accordingly.

Although delayed, biofuel demand will cause more biofuel production capacity (+), which in turn will increase biofuel production (+) (provided that the biofuel industry is in a position to respond). Biofuel production, as the core of the model, is the driver to nine feedback loops, involving various sectors. Starting with R2, indicated in green, it can be seen how an increase in biofuel production will lead to more energy being required (which will increase emissions) and lead to an increased biofuel production cost (+). The increased production cost will oppositely (−) affect the profitability of biofuel and thus lead to a lower GDP, investment into biofuel and production capacity, ultimately decreasing biofuel production.

R3 shows how an increase in biofuel production will increase the feedstock requirement and agricultural land use, increasing (+) the biofuel production cost and following the same feedback loop as R2 to biofuel production. Similarly, R4 shows how an increased biofuel production will increase water demand and production cost, ultimately leading to decreased biofuel production based on reduced profitability.

B2 is a balancing loop and shows how an increase in biofuel production will cause the cumulative biofuel production to increase, which contributes to the learning curve and the more the learning curve, the less (−) the biofuel production cost (i.e. the longer biofuel has been produced, the more efficient the people and processes involved will become). This lower production cost will then lead to increased profitability, GDP contribution and investment into biofuel, which in due course leads to more biofuel being produced.

R5 shows a direct causality between biofuel production and profitability, while an increase in by-product produced (R6) also contributes to increased profitability of biofuel, as more by-product will become available with more biofuel being produced. The increase in profitability leads back to reinforce biofuel production along the same causal path followed by B2. R7 shows how the increased by-product due to biofuel production will lead to more employment and thus increased GDP, investment into biofuel production capacity and production. R8 indicates that biofuel production directly causes additional employment in the biofuel industry, which will directly provide reinforcing feedback by increasing biofuel production. R9 shows similar behaviour to R7, where the employment created ultimately leads to more biofuel being produced.

The last causality to be discussed does not form a feedback loop, but plays a key role in the CLD, as it connects two of the major indicators of the model. This connection shows how an increase in biofuel production will lead to decreased fossil fuel use, which will lead to decreased emissions (assuming that the additional emissions from agricultural land use and electricity demand does not outweigh the emission reduction due to biofuel use).

3.3.3 Leverage and Intervention points

Through investigation of the literature on biofuel and the conceptual approach followed, some preliminary intervention points can be identified. Combining the fact that the rising electricity costs in SA have been of a major concern in many industries with the observation that energy requirement is part of the core of the biofuel model, energy requirement is highlighted as the most influential endogenous factor.

The practical constraints imposed by the production process, confine the other key leverage points to be exogenous. One of these points is the by-product selling price. Although the selling price is determined by the market, by making use of the pre-fractionation method, it is possible to produce a by-product of a higher quality and thus reaching a higher market value. Additional value streams are also looked at, and du Preez (2015) identified that if one was to combine the biofuel production with electricity sales, it would be possible to reduce energy costs while simultaneously generating additional income from the sale of surplus energy. du Preez (2015) proposes building an on site combined heat and power (CHP) plant which can also capitalise on the governments Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), which offers purchasing agreements to companies producing renewable energy.

The other two exogenous factors that are likely to be highly influential in the business case of biofuel production are biofuel selling price and feedstock purchasing price. These prices cannot be controlled by the producer in any way, meaning that the upper and lower limits of these values that would still return a feasible business case should be investigated and considered.

3.4 Dynamic Modelling

Cavana and Maani (2000) mentions that although the dynamic modelling phase can follow directly after the problem identification, deeper insights into dynamic modelling can be gained after completing the causal loop modelling. The dynamic modelling is shown in the sections to follow and entails the stocks, flows and drivers for the variables and indicators of the biofuel production system. Vensim® software is used to show the interactions of biofuel production within the Western

Cape Province over time. The model and the indicated effects are then validated and tested for sensitivity in order to conclude on the scenarios that would provide the most insight into biofuel production strategies.

3.4.1 Model Building

The subsections below indicate the models that represent the effects of biofuel production within the Western Cape Province. Subscripts are used in Vensim®, which allows the modeller to build one model structure, but simulate the results with different inputs for both bioethanol and biodiesel. The model structure is thus discussed by referring to biofuel, while the results discuss the outcomes for bioethanol and biodiesel respectively. It has been mentioned that the time frame for the simulation is from 2001 to 2040 and is thus represented in the equations by t_0 and t_n. The equations indicate the main stock and flow of every sub-model, while some of the most important influential factors are also discussed. Note that this section explains the logic behind the models, while the actual input parameters are explained in detail in Section 3.5.3.

3.4.1.1 Biofuel Production

Biofuel production is simulated by two main stocks, of which the first one is *Annual Biofuel Capacity Refinement* (RC) and the second is *Accumulated biofuel production* (AB). Equation 3.4.1 shows the annual refinement capacity increasing by the rate at which new capacity (r_{nc}) is constructed and decreasing with the rate at which the current capacity degrades (r_{dc}). The amount of new capacity constructed is initially determined by a strategic decision to construct a plant and then influenced by the effect of feedstock availability. Degradation of the plant capacity is determined by the expected life of a biofuel plant and influenced by the effect of maintenance on the expected life. $RC(t_0)$ is the initial value of biofuel refinement capacity, which is *zero* in the case of the Western Cape Province.

$$RC(t) = RC(t_0) + \int_{t_0}^{t_n} [r_{nc} - r_{dc}]\mathrm{d}t \tag{3.4.1}$$

Accumulated biofuel production is a stock which can only be increased by biofuel production *(r_{bp})* as shown in Equation 3.4.2. Learning curves involved in facilities (like production efficiency) are usually based on the amount of accumulated biofuel produced, as they are a more specific indicator of the learning curve than the conventionally used operational years.

$$AB(t) = AB(t_0) + \int_{t_0}^{t_n} r_{bp} \mathrm{d}t \tag{3.4.2}$$

The rate of annual biofuel production is determined by taking the minimum value of the available refinement capacity and the theoretically available amount of biofuel (based on the feedstock available) i.e. one cannot produce more than the available capacity nor than the actual feedstock available allows. Biofuel production is used throughout most of the other sub-models as it largely influences operational costs. Biofuel production, as a sub-model, can be seen in Figure C.1, where all the drivers are indicated.

3.4.1.2 Agricultural Yield

The agricultural yield is a sub-model that makes up part of a larger[8] agriculture model for the Western Cape Province. The agricultural yield and land models have numerous stocks and flows, where models interact with one another to simulate the expected yield and land for specific crops cultivated in the Province. For simplicity, the results of the agricultural yield simulation were exported and used as a lookup table in the biofuel production model, where the available land and yield factors influence the amount of feedstock available for biofuel production (refer to Appendix C.1 for the agriculture model results that were used).

3.4.1.3 Biofuel Expenditure

It is equally important to consider operating costs and initial investment when evaluating the business case for biofuels. The long-term success of a biofuel plant depends strongly on the daily operating performance in terms of quality, yields and efficiency. The biofuel expenditure sub-model is presented by Equation 3.4.3, where it can be seen that biofuel expenditure increases annually by the OPEX and the repayment of the capital loan.

$$BE(t) = BE(t_0) + \int_{t_0}^{t_n} [r_{OPEX} + r_{CAPEX}] \mathrm{d}t \tag{3.4.3}$$

The OPEX includes feedstock cost, water cost, chemical cost, maintenance cost, labour cost and energy costs, as shown in Figure C.4. The annual CAPEX is

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[8] The WeCaGEM model was presented at the 33rd International Conference of the System Dynamics Society held in 2015 at, Cambridge, Massachusetts, USA (Musango *et al.*, 2015).

modelled as a loan, repaid over the initial expected lifetime of the facility (20 years). Equation 3.4.4 shows how the annual capital repayments are calculated. The compound interest formula is used and divided through the expected lifetime to result in equal annual payments, ultimately amounting to the original CAPEX plus interest paid.

$$CAPEX_{AR} = \frac{CAPEX \cdot \left(1 + \frac{rate}{periods}\right)^{time \cdot periods}}{time} \tag{3.4.4}$$

where:

$time$ = 20 years
$periods$ = 12 months
$rate$ = annual interest rate

3.4.1.4 Operational Finances

The operational finances sub-model simulates the various price increases that are used as inputs throughout the model. These operational costs include the following:

i. Biofuel crop feedcost;
ii. Technical and Administrative staff wages;
iii. Management salary;
iv. Water unit cost;
v. Electricity cost;
vi. Combustibles cost;
vii. By-product selling price; and
viii. Real value of assets.

All of the above mentioned stocks increase over the simulation period, as the generic form of Equation 3.4.5 suggests, where $Price(t_0)$ indicates the price in 2001 and r_{PI} represents the annual increase in price, based on the price inflation. The stocks increase with annual estimates recommended by literature. The Biofuel Crop Feedstock cost also takes supply and demand effect on cost into account.

$$Price(t) = Price(t_0) + \int_{t_0}^{t_n} r_{PI} \mathrm{d}t \tag{3.4.5}$$

The various stocks and flows representing the escalating costs can be seen in Figure C.5.

3.4.1.5 Profitability

The main aim of the profitability sub-model is to indicate the overall profitability of biofuel production and the subsidy required. It was mentioned that the subsidy will serve as incentive to attract investors, by covering the gap between actual market-related earnings and the earnings required to achieve the 15% ROA. The profitability model has one main stock diagram *Expected Accumulated Biofuel Profit (EABP)* representing the overall profit made by biofuel production, as indicated by Equation 3.4.6. This value will become negative if a loss is made through biofuel production. The EABP increases with the *annual profit after tax (*r_{PAT}*)* and does not include the subsidy (if required) as part of the profit.

$$EABP(t) = EABP(t_0) + \int_{t_0}^{t_n} r_{PAT} \mathrm{d}t \tag{3.4.6}$$

The drivers of the biofuel profitability are extremely important and these include the BFP (which influences the biofuel selling price) and other revenue streams. Figure C.6 shows how the various revenue streams are determined and how OPEX is subtracted from this to provide the *Gross Profit*. The gross profit is then used to calculate the IRR and the ROA, where the ROA can be used to calculate the subsidy required.

3.4.1.6 Alternative to local production

The alternative to local production sub-model is used to compare local biofuel production to the alternative. The alternative evaluates the cost of purchasing and transporting biofuel from an existing biofuel plant elsewhere in the country. Bioethanol is assumed to be from the Mabele fuels plant in the Freestate Province and biodiesel from one of the two plants planned in the Eastern Cape Province. The accumulated transportation cost and purchasing price is then compared to the local cost of production. Equation 3.4.7 indicates how the stock *Bottom Line Cost for Blending Mandate (BLC)* is increased by the *Nett annual cost of biofuel* *production in the Western Cape (Local)* or the *Buying of biofuel from another Province (Buy).*

$$BLC(t) = BLC(t_0) + \int_{t_0}^{t_n} [S \cdot r_{Local} + S1 \cdot r_{Buy}]\mathrm{d}t \tag{3.4.7}$$

where:

$$\text{Local production} \Rightarrow S = 1 \text{ and } S1 = 0$$
$$\text{Buying of biofuel} \Rightarrow S = 0 \text{ and } S1 = 1$$

Figure C.7 shows the drivers influencing the bottom line cost, as well as a simulation making use of a fuel demand[9] model to indicate the shortage or oversupply of biofuel in order to meet the blending regulations.

3.4.1.7 Employment

Amigun *et al.* (2012) mentions that labour is very dependant on the production scale and the level of automation present in the plant. The type of process (batch or continuous) and level of sophistication involved in the operation also has a large influence on the operating labour. The scope of employment creation should also be pre-determined (i.e. direct, indirect and induced).

The employment sub-model takes a basic approach to employment creation through biofuel production and only considers direct additional jobs created. The biggest portion of employment creation through biofuel production is normally in the agricultural sector, but with the Western Cape Province having such a well established agricultural sector, only the additional marginal (previously uncultivated land) will be considered as contributing to new employment creation in the agricultural sector.

Figure C.8 shows how the direct employment is influenced by the number of technical, cleaning, administrative and security personal employed per biofuel production capacity. The number of management employees contributing to employment creation is taken as a fixed number, based on information from operating biofuel plants.

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[9] The WeCaGEM model was presented at the 33rd International Conference of the System Dynamics Society held in 2015 at, Cambridge, Massachusetts, USA (Musango *et al.*, 2015).

3.4.1.8 Emissions

The main stock and flow of the emissions sub-model shows the nett carbon carbon dioxide emissions due to biofuel production as *Cumulative Biofuel Emissions (CBE)*. From Equation 3.4.8, it can be seen that the *CBE* will increase with the *Yearly Air Emissions* (r_{YAE}) and decreases with the *Air Emission Decomposition* (r_{AED}).

$$CBE(t) = CBE(t_0) + \int_{t_0}^{t_n} [r_{YAE} - r_{AED}]\mathrm{d}t \tag{3.4.8}$$

Figure C.9 shows how the same switch (*S and S1* used in the employment sub-model) is used to compare the annual emissions caused by local production to buying in biofuel[10]. The main contributors to biofuel production emissions are in the form of process energy generation, transportation and agricultural emissions. The use of biofuel does however displace a large amount of fossil fuel, which avoids combustion and transportation emissions of these fossil fuels. The quantification of carbon emissions is a difficult process, due to the many unknowns involved in the cradle-to-grave process, like the system boundary and the extent of up- and down-stream activities. The model in this study thus focusses mainly on direct emissions.

3.4.2 Model Behaviour and validation

Senge (1980) mentions that before a model can be used for policy testing and evaluation, one must have enough confidence in the model to be sure that the results obtained are accurate and useful. A variety of validation techniques have to be used in order to build confidence in a system dynamics model as no single test can ensure validity. Three different areas of the model should be tested and these include investigating the soundness of structure and parameters, behaviour and outcomes (Maani and Cavana, 2007). In order to address all the aspects of validation, the sections to follow discuss some of the most pertinent validation techniques as recommended by Senge (1980).

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[10] The study assumes that the production process of the existing fuel plant will cause emissions equal to that of the local production scenario. The only additional emission will thus be caused by transportation of biofuel.

3.4.2.1 Model Structure

In order to verify the structure of the model, it has to be compared directly to the real system that it presents. This was done by consulting with experts in the system dynamics and biofuel field, respectively. Industry specialists, academics and peers were consulted and valuable inputs were gained. A preliminary model was presented at a conference[11] to gain some further insights and critiques on the model structure. The wide variety of backgrounds and perspectives of the inputs received, ensured that the structure of the model closely resembles that of the real life situation and that the assumptions and exclusions of the model are valid and do not contradict any knowledge of the real system. The model structure also compared well to another biofuel model that was independently developed by Musango *et al.* (2012).

3.4.2.2 Parameters

The model parameters are compared to real life values. Although the constants and exogenous inputs were mainly gathered from SA specific studies, cross referencing and triangulation with values given by world leaders in biofuel production were often performed. Although it would be expected that these values are not exactly the same as those of the South African studies, close relations were witnessed.

As part of structure and parameter evaluation, it is important to compare the model to operating biofuel production facilities. This was done by evaluating the model inputs and outputs against that of operational American biofuel producers, where a parallel was drawn between triticale and wheat use for bioethanol and rapeseed and canola for biodiesel. The model inputs used can be seen in Section 3.5.3.

3.4.2.3 Extreme Conditions

The extreme condition test is useful in indicating logic flaws within the model, like upper and lower limits or non-linearities that form part of the real world that are not accounted for with the model. The extreme condition test is also very useful in identifying the range of reliability or confidence of a model, which is especially advantageous in policy testing. The extreme boundary test enables one to test the model over a normally expected operating range, and then at extreme conditions, to see to what extent policies can be tested.

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[11] The model on Bioethanol production in the Western Cape was presented at the 24th Annual IAMOT Conference in 2015 in Cape Town, SA (Jonker *et al.*, 2015).

The extreme condition test is thus firstly used to ensure conservation of flow by setting inputs like *biofuel capacity* or *land availability* to zero. The model was then simulated and it was confirmed that all of the expected variables like *biofuel production, energy requirements, water requirements* etc. were also zero. The plausibility of the model over the normal expected range was confirmed by simulating a variety of different facility sizes *capacity construction* and evaluating whether the outcomes were in the expected regions by comparing to real life facility data. Some of the parameters used are not based on production volumes, but are time based instead, which is due to certain construction assumptions that are mentioned in Section 3.5.3. These assumptions might limit the model when evaluating the impact of larger facilities (in excess of 250 million litres per year). The model was built to evaluate specific projects for the Western Cape Province, of which the feasibility has been investigated and larger facilities are not likely to be feasible (the model also indicates this) due to the feedstock and land availability constraints within the Province.

3.4.2.4 Boundary-Adequacy

Boundary adequacy is used to provide confidence in model structure, behaviour and policies. Focusing on model structure, this is done to determine whether the level of aggregation and separation used in the model is appropriate, and that a realistic resemblance of real life can be provided at the said level of aggregation. In the light of this study being a project and policy evaluation, the model looks at a high level of detail (for example; by identifying individual drivers for production and operational costs). The model is limited in its holistic encapsulation, as a fully detailed energy, water, employment, GDP and agriculture model that considers the feedback of the biofuel industry would be required. The model's boundary does however include the adverse effects on the most important indicators as defined in Section 3.3.1. The model boundary thus coincides with the model purpose, although deeper insights into biofuel production in the Western Cape Province could be gained if the model boundary is broadened.

3.4.2.5 Dimensional Consistency

The assignment of dimensions to parameters and variables help to ensure that all of the parameters that are used are in fact necessary and meaningful. Occasionally it occurs that manipulative variables are used to force model behaviour to follow expected behaviour, but by ensuring dimensional consistency, these manipulative variables are easily identified and should thus only be included in a manner that can be justified from real life estimations. In the case of valid real life estimations and scale factors, the dimensional consistency will hold true.

The units were evaluated after each new variable and parameter was added to the model to ensure that dimensions were consistent and represented reality. Ensuring that units were correctly used formed part of the parameter test, and values along with their dimensions were compared to information obtained from various literature sources and operational production facilities.

Based on the importance of unit consistency, the Vensim® software package has a built-in unit check functionality. The unit check function was used regularly and after final completion of the model construction to ensure there were no unit errors present and only meaningful parameters with their appropriate dimensions were used to influence model behaviour.

3.4.2.6 Model Behaviour

The structure of the model is further investigated by looking at model behaviour produced by the structure. Senge (1980) recommends the following behavioural tests: behaviour reproduction, prediction, anomalies, surprise behaviour extreme policies and behaviour sensitivity.

Forrester (1961) critiques the use of point-by-point reproduction and statistical coherence of real life as a validation technique. It is however useful to compare model outcomes to historical data observed in order to observe the appropriateness of model behaviour. If model behaviour deviates drastically (with regards to trends and order of magnitude) from that of the historically observed data, it is obvious that drivers and parameters that form part of the model structure do not accurately present the system. Figure 3.4 shows how the model simulates the price of electricity in SA compared to the historic values, and it can be concluded that although the simulation does not fit the data with complete accuracy, the values and trends are behaving as expected, which gives confidence in the logic and model structure. A similar comparison was done for the BFP simulation as shown in Figure 3.5.

The amount of variables that could be compared to historical data was limited due to the lack of available data on the biofuel industry in SA. The behaviour of each variable was studied to ensure that the expected trends were witnessed and that the interaction of variables were logical. Changes in trends (fluctuations) and patterns were investigated and could be logically explained. This is discussed in detail in the Modelling Outcomes discussion in Section 4.

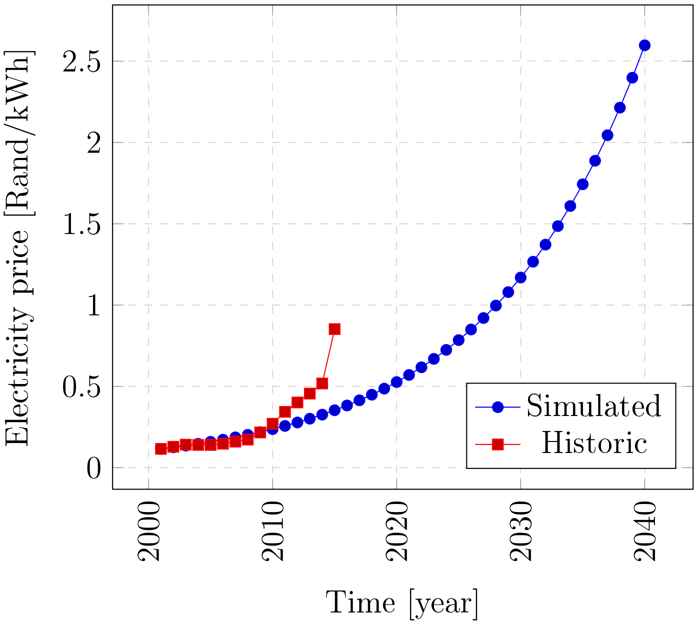

Figure 3.4: Electricity Price - SA

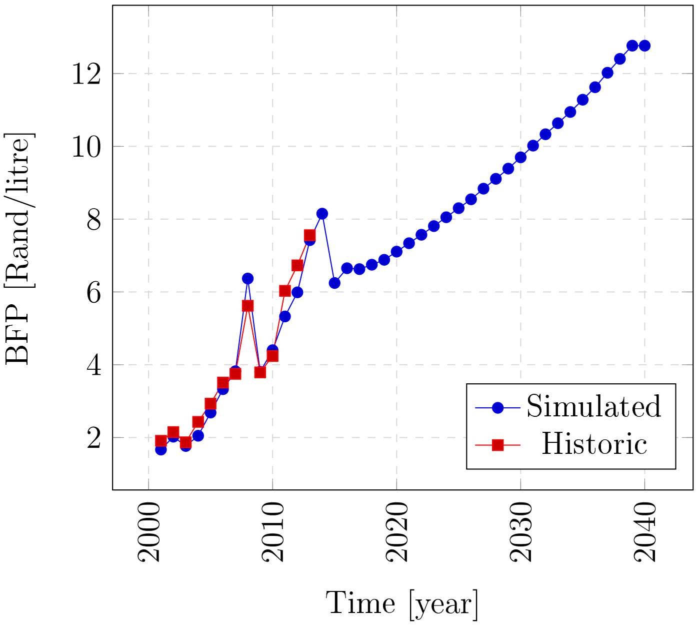

Figure 3.5: Basic Fuel Price - SA

3.4.2.7 Other Validation Techniques

In addition to the model structure and parameter validation, external or independent validation tools are also available. The System Dynamics Model Documentation and Assessment Tool (SDM-Doc) is a HTML-based tool, developed at Argonne, to help modellers increase the transparency of models (Martinez-Moyano, 2012). SDM-doc assesses and summarises a model based on three categories, namely model information, warnings and potential omissions.

Appendix D shows the detail of the model under the three categories. The first category provides information regarding the size and complexity of the model, as well as the model settings used, to provide transparency into the modelling process.

The second section provides warnings on equations that failed a set of certain documentation and formulation tests. *Undocumented equations* are equations that do not provide a description of what the equation entails. Although 164 of the 226 variables are undocumented, the variables and equations were named in a way that is very descriptive and will avoid any ambiguity. *Equations with embedded data* are equations where hard typed data was found in the equation. Fixed values within equations reduce the dynamics of the system and should exist only as constants. The high number of embedded values (41) can be accounted to the high amount of stocks and switches used, which are unavoidable. No unit errors were found, all variables defined were used in the model, and subscripted values were also completely defined.

Non-monotonic Lookup functions are lookups where the slope is not constantly positive or negative and can cause ambiguous causal relations between inputs and outputs. Seven monotonic lookup functions are present within the model. This is due to the input received from other models that were used as lookup functions. The dynamics and complexity of lookups like land availability and demand and supply curves are expected to have some variability and changes in slope. Equations using IF THEN ELSE and MAX or MIN functions are highlighted, as these functions can influence the dynamic behaviour of the system. The high number of IF THEN ELSE statements within the model are however necessary due to biofuel production and construction only starting at a predetermined time and a high number of switches that are used to evaluate different scenarios.

Lastly, looking at potential omissions, no unused variables were found and 10 supplementary variables were identified, which are used for informational and validation purposed within the model. No supplementary variables are used as part of the model. Nine complex variable formulations were found, which means that nine equations have more than three inputs. To ensure transparency, equations with more than three inputs were avoided as far as possible. However, some financial equations like annuity costs and IRR calculations are complex and require more than three inputs to be used at once. The amount of switches and IF THEN ELSE functions further contributed to the equations having more than three inputs and were unavoidable.

SDM doc provides a thorough overview of the entire model and assists the modeller to systematically work through the logic of the model. This ensures that the complexity of the model holistically captures the dynamics of the real life system, while still providing enough transparency for an independent modeller to reach the same outcomes if the same process is followed.

3.4.3 Model Sensitivity and Strategies

Identifying key leverage points in biofuel production in the Western Cape Province is one of the most important outcomes of the model. Identifying areas that will lead to the greatest improvement in biofuel feasibility is done through a sensitivity analysis. The sensitivity analysis in Vensim®, makes use of the Monte-Carlo technique and by performing the test on various variables, it was possible to identify the variables that could have the biggest influence on the feasibility of biofuel production.

The various scenarios and their inputs are discussed in Section 3.5.2 and 3.5.3, respectively. The base case scenario was simulated (where it was assumed that a conventional[12] biofuel facility is constructed and operated) and the sensitivity of the *Gross Profit* was systematically tested on a variety of variables. *Electricity cost increase* showed a large influence on the Gross Profit. This, coupled with the recent publications of expected electricity price increases, lead to the identification of the electricity price to be one of the key intervention points for biofuel production in the Western Cape Province. The outcomes of the sensitivity analysis on electricity price increase (between 3-12.5% per year) can be seen in Figure 3.6 and 3.7.

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[12] A conventional biofuel facility in this study is considered to be one that uses grid provided electricity for operation and a coal fired boiler for process heat.

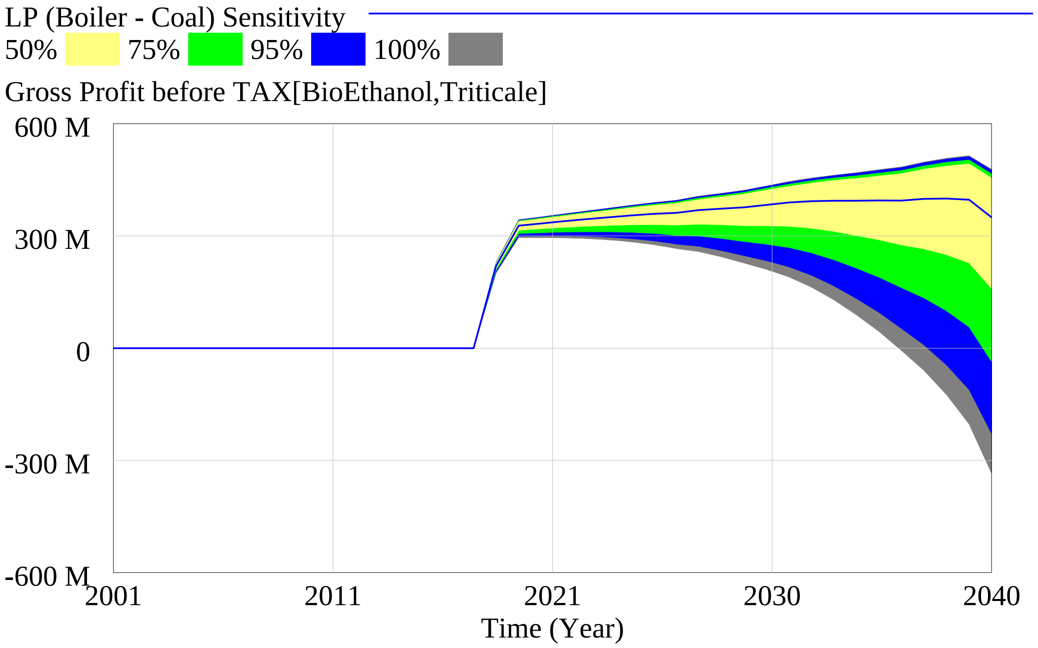

Figure 3.6: Gross Profit - Bioethanol - Electricity price sensitivity

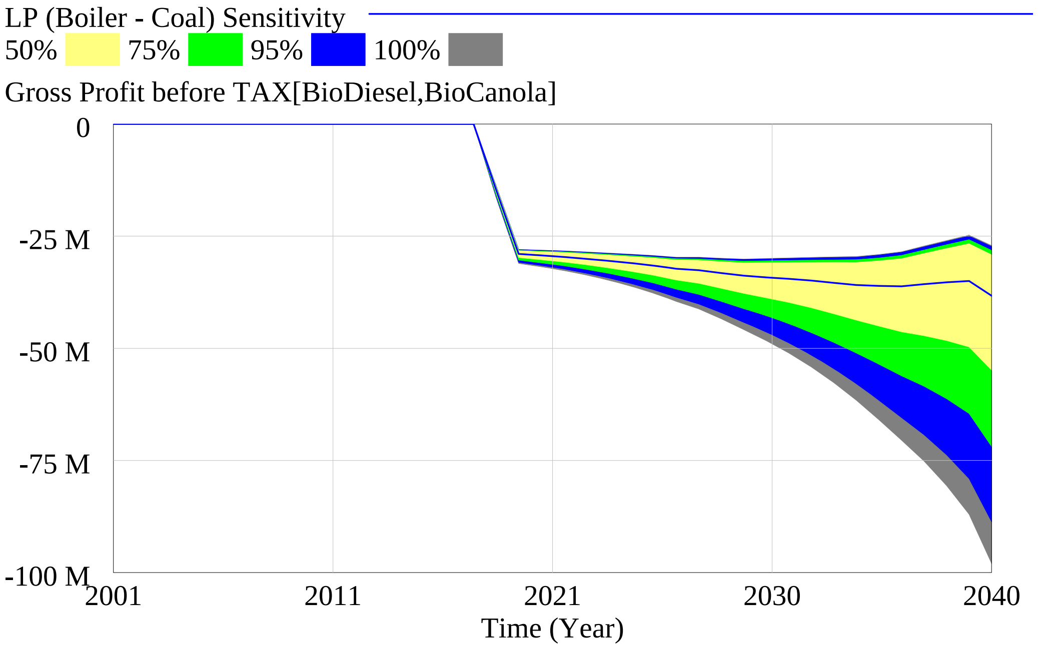

Figure 3.7: Gross Profit - Biodiesel - Electricity price sensitivity

Other variables like *feedstock cost, BFP and by-product selling price* were also found to be influential in the business case of biofuel production. However, the parameters of these variables are determined exogenously and subsequently from a project evaluation perspective, these will not form part of the scenario evaluation.

3.5 Scenario Planning

In developing the scenarios for modelling, one usually tests the policy by selecting a single appropriate internal variable and changing this variable based on certain expectations of what the business as usual (BAU), best and worst case scenarios would look like. For the project and policy evaluation in this study, the process is adapted based on the fact that the BAU scenario for biofuel production would not provide any new insight. The sections to follow explain how the scope of the scenarios used for the project and policy evaluation was identified and how the various scenarios will give insights for strategic decision making with respect to implications of the biofuel blending mandate for the Western Cape Province.

3.5.1 Scenario scope

The major model assumptions that will drive all of the scenarios are related to the planned capacity and time frame of the biofuel production facilities.

Based on the information discussed in Section 3.2.3, the model assumes that a bioethanol production plant that can produce 160 million litres per year will be constructed (commencing in 2016) and completed by 2018. The plant will make use of triticale as feedstock, which will be grown on the available marginal land, as well as in crop rotation[13] of triticale on a four year cropping cycle.

The biodiesel production simulation is based on the assumption that a biodiesel facility capable of producing 35 million litres per year will be completed by 2018. The facility will make use of 25% of the Province's canola production. The interaction between bioethanol and biodiesel production facilities is considered to be negligible and the implications of each plant are considered in isolation.

For the local production scenarios, the simulation was mainly concerned with indicating the water, energy and cost implications based on biofuel production, as well as identifying the constraints present in the system. The model was set up to form part of a bigger model, but due to the lack of energy, water, economy and

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[13] Farmer uptake is considered and based on the income achieved by triticale compared to B3 wheat i.e. not all farmers will incorporate triticale as part of their crop rotation scheme.

employment models that can incorporate the feedback effects of biofuel production, the boundary was confined to production requirements and constraints.

It was mentioned that for the Western Cape Province to form part of the blending mandate, a scenario has to be considered where biofuel is bought in from existing biofuel production plants. The comparison of local production versus buying biofuel is limited to bottom line cost implications, employment creation and emissions.

3.5.2 Expected Scenarios

Based on the key variables, sensitivities and boundaries identified, along with the recommendations of du Preez (2015), energy use is considered as one of the major intervention points. The other strategic decision is whether biofuel should be locally produced *(LP)* or not *(NLP)*. The scenarios that follow attempt to show the various impacts and implications of the key points addressed.

3.5.2.1 Scenario 1: LP (Boiler-Coal)

The first scenario considers the most likely local production scenario, where grid electricity will be used for operation of the facility and a boiler making use of coal is used to generate process heat. All of the local production scenarios make use of locally sourced feedstock and production volumes will be constrained by the production capacity available of feedstock availability.

3.5.2.2 Scenario 2: LP (Boiler-Biomass)

Scenario 2 is the same as scenario 1, where a boiler is used for process heat, but the combustible used for the boiler is locally sourced biomass. This scenario is included as the combustion of biomass is considered carbon neutral, which contributes to the sustainability of biofuel use and production. The use of biomass can also form part of the alien invasive land clearing scheme, which further contributes to overall sustainability, due to the negative effects of alien invasive species on the environment.

3.5.2.3 Scenario 3: LP (CHP-Coal)

This scenario is based on the work of du Preez (2015) and looks at an alternative to using grid provided electricity. While most of the parameters are the same as for the previous two local production scenarios, this scenario simulates the effect of incorporating an on-site CHP plant (33 MW capacity) as part of the production facility. The CHP plant uses coal as a combustible, and will provide electricity and process heat for the production process. Excess electricity produced on-site is assumed to be sold back into the grid. It is expected that the CHP scenario has added benefits, improving the feasibility of biofuel, but will be weighed against the additional CAPEX required.

3.5.2.4 Scenario 4: LP (CHP-Biomass)

The fourth scenario assumes the same CHP plant in the production facility as in scenario 3, but uses biomass as combustible. As mentioned earlier, the use of biomass contributes to sustainability of production and where it is used for electricity production, it could strengthen the business case of biofuel production. This is based on the notion that electricity produced by making use of biomass can achieve a higher selling price if it conforms to the requirements of the National Renewable Energy scheme.

3.5.2.5 Scenario 5: NLP (Coal)

A non-local production scenario is also considered to indicate and compare the bottom line costs and emissions of purchasing biofuels from existing plants to comply with the blending mandate regulations. The first non-local production scenario assumes that the same production parameters are used as with scenario 1, where the existing biofuel producer makes use of grid electricity and a coal fired boiler for energy.

3.5.2.6 Scenario 6: NLP (Biomass)

The last scenario is similar to scenario 5, where non-local production is considered. It is however assumed that biomass is used to fuel the boiler of the operational biofuel producer where biofuel will be sourced from. This scenario is unlikely as no mention is made of using biomass in the proposed plants. The scenario is however included to provide a non-biased comparison with all parameters being equal.

3.5.3 Model Inputs and Assumptions

This section aims to provide some insight and transparency into the model parameters and the general assumptions made. These values correlate to those identified in Section 3.2.3, although scaling factors were sometimes used to obtain the values for the specific plant size. Table 3.5 shows the general parameters that are used in the base model for all of the scenarios and then some scenario specific parameters, which support the assumptions explained in the previous section. These parameters are used as exogenous values that drive and define the model and system structure.

In addition to the revenue and operational cost, CAPEX is one of the key factors influencing investment and subsidies. The table indicates the CAPEX for the boiler and CHP scenarios. The biodiesel plant construction cost is based on the estimations for a Seed Extraction Biodiesel Plant as studied by Nolte (2007), where it was noted that a plant (producing 25 million litres per annum) will cost between 100 - 145 million. The biodiesel CAPEX was thus obtained by scaling the average cost for a plant producing 35 million litres per annum. The cost of the bioethanol production facility is based on the work of Amigun *et al.* (2012). As expected, the CHP scenario will require additional capital investment and this was estimated by du Preez (2015) to be between R51000 - R58000 per installed kW. This study assumed that a 33 MW unit will be constructed at R58000 per kW. The CAPEX is assumed to be equal to the total assets, and these assets are depreciated on a straight line basis over 20 years, as per the Draft position paper on the South-African biofuels regulatory framework (Department of Energy, 2014).

The NLP scenarios assume that bioethanol and biodiesel are transported from the Freestate and Eastern Cape Provinces respectively, as per the planned projects. In addition to the general and scenario specific assumptions, Table 3.6 shows the exogenous variables in terms of Economic, Environmental and Social sectors. The parameters were gathered from various sources of previous studies and were validated with current data where possible.

The BFP is determined by a variety of costs, where the exchange rate and the brent crude oil price are the main drivers. The model uses the crude oil projections by the U.S. Department of Energy (2015) and the historical exchange rate, where a constant exchange rate is assumed after 2015, as indicated.

Table 3.5: General and Scenario specific inputs

	Input
General	
Capacity - Bioethanol (litres/year)	160 million
Capacity - Biodiesel (litres/year)	35 million
Normal Expected life of biofuel plant	20
Bioethanol yield per ton of feedstock (litre/ton)	470
Biodiesel yield per ton of feedstock (litre/ton)	454
Operational Days per year (days)	330
Operational Hours per day (hours)	24
By - product produced per ton triticale processed (ton/ton)	0.248
By - product produced per ton canola processed (ton/ton)	0.55
Process heat required per litre - BioEthanol (MJ/litre)	15.5
Process heat required per litre - BioDiesel (MJ/litre)	0.8
Litres per oil barrel (litres/barrel)	160
Nautical distance from Saudi -Arabia to Cape Town (km)	8616
Crude oil density (@ 15°C) (kg/litre)	0.8658
Chemical required - Yeast (kg/litre)	0.0013
Chemical required - Enzyme (kg/litre)	0.0009375
Chemical required - Methanol (kg/litre)	0.164032
Chemical required - Catalyst (kg/litre)	0.00528
Scenario Specific	
LP Boiler - Coal/Biomass	
CAPEX - Bioethanol (rand)	R 900 million
CAPEX - Biodiesel (rand)	R 200 million
Heating Value Coal (MJ/ton)	20380
Heating Value Biomass (MJ/ton)	9300
Electricity required - Bioethanol (kWh/litre)	0.495
Electricity required - Biodiesel (kWh/litre)	0.207
LP CHP - Coal/Biomass	
CAPEX - Bioethanol (rand)	R 2 810 million
CAPEX - Biodiesel (rand)	R 2 120 million
Combustible required - Coal (ton)	164255
Combustible required - Biomass (ton)	367897
Surplus Electricity Sales - Coal (rand/kWh)	0.67
Surplus Electricity Sales - Biomass (rand/kWh)	1.4
NLP - Coal/Biomass	
Biofuel transport differential (Rand/litre)	0.35
Estimated bioethanol transport distance (km)	1200
Estimated biodiesel transport distance (km)	767

Table 3.6: Economic, Environmental and Social parameters

	Input
Economic	
Wheat Transport differential (Rand)	600
B3 wheat price penalty (%)	8
Wheat Price (Rand/ton)	Agriculture model - Lookup
Maintenance as percentage of CAPEX (%)	1.5
Loan Interest Rate (%)	9.25
Loan repayment time (years)	20
By - product selling price - Increase rate (%/year)	8
Labour cost -Increase rate (%/year)	4.6
Water cost - Increase rate (%/year)	5
Electricity cost - Increase rate (%/year)	8
Combustible price - Increase rate (%/year)	5
Chemical price - Increase rate (%/year)	8
Feedstock cost - Increase rate (%/year)	5
Projected Oil price	Lookup
Oil price ($/barrel)	Lookup - relative to projected oil price
Exchange rate (Rand/$)	Lookup - constant @ R11.54/$ after 2015
Depreciation Rate (%)	Straight line over 20 years
Tax rate (%)	29
Biofuel cost per litre (% of BFP)	100
CO_2 decomposition factor (%)	0.1
Environmental	
Fraction of harvest expected to be B3 or lower (%)	31
Crop Rotation Cycle time (years)	4
Total Planted Grain area (ha)	Agriculture model - Lookup
Total Canola production area (ha)	Agriculture model - Lookup
Triticale Feedstock yield per ha (ton/ha)	2.5
Canola Feedstock yield per ha (ton/ha)	1.3
Initial process water requirement (litre/litre)	23.5
Water required per litre of bioethanol produced (litre/litre)	2.63
Water required per litre of biodiesel produced (litre/litre)	2.23
Marginal land avaiable (ha)	70000
CO_2 emission per ha triticale ($kgCO_2$/ha)	2190
CO_2 emission per ha canola ($kgCO_2$/ha)	1514
CO_2 emission per payload quantity ($kgCO_2$/km.ton)	0.0639
CO_2 emission per nautical payload($kgCO_2$/km.ton)	0.016
CO_2 emission coal ($kgCO_2$/ton)	2300
Fossil Fuel - Petrol Emission ($kgCO_2$/litre)	2.328
Fossil Fuel - Diesel Emission ($kgCO_2$/litre)	2.614
Bioethanol - Emission ($kgCO_2$/litre)	1.503
Biodiesel - Emission ($kgCO_2$/ton)	2.486
Social	
Management Staff (persons)	4
Employment ratio per capacity (person/litre)	3.74E-07
Agricultural area per permanent worker (ha/person)	33.64

Chapter 4

Modelling Outcomes

The previous section discussed the model structure development and validation, as well as the input parameters and the scenarios identified for the project evaluation. The identified scenarios were simulated by making use of switches[1] within the model and results for both bioethanol and biodiesel production are discussed below.

4.1 Simulation Results

The graphic illustration of simulated results are limited to the key indicators, although additional insights are gained and discussed from lower level investigation. The driving forces and factors influencing model behaviour are assessed and discussed.

4.1.1 Biofuel Production

Figure C.1 shows the factors influencing biofuel production. The factors that determine and constrain the amount of biofuel produced are mainly the production capacity and the amount of feedstock available, where feedstock is dependant on land availability and agricultural yield. Therefore, biofuel capacity and production were nearly identical for all of the scenarios and different scenarios are thus not indicated in this section.

From Figure 4.1 it can be seen that the bioethanol production volume is constrained by the amount of feedstock available. The graph shows the capacity of the bioethanol plant continuously exceeding the amount of ethanol produced,

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[1] By assigning a value of one or zero to a variable an on/off switch is effectively created, through which certain events can be turned on or off in a selected scenario.

although the capacity and production are slowly converging, due to the maintenance and the feedstock availability effect on capacity. The simulation further indicates that bioethanol production in the Western Cape Province is unlikely to reach volumes of more than 120 million litres per annum with the current land allocation and yield assumptions. This is supported by Figure 4.2, which shows roughly 30000 ha of land allocated towards triticale growth as part of crop rotation schemes in the Province.

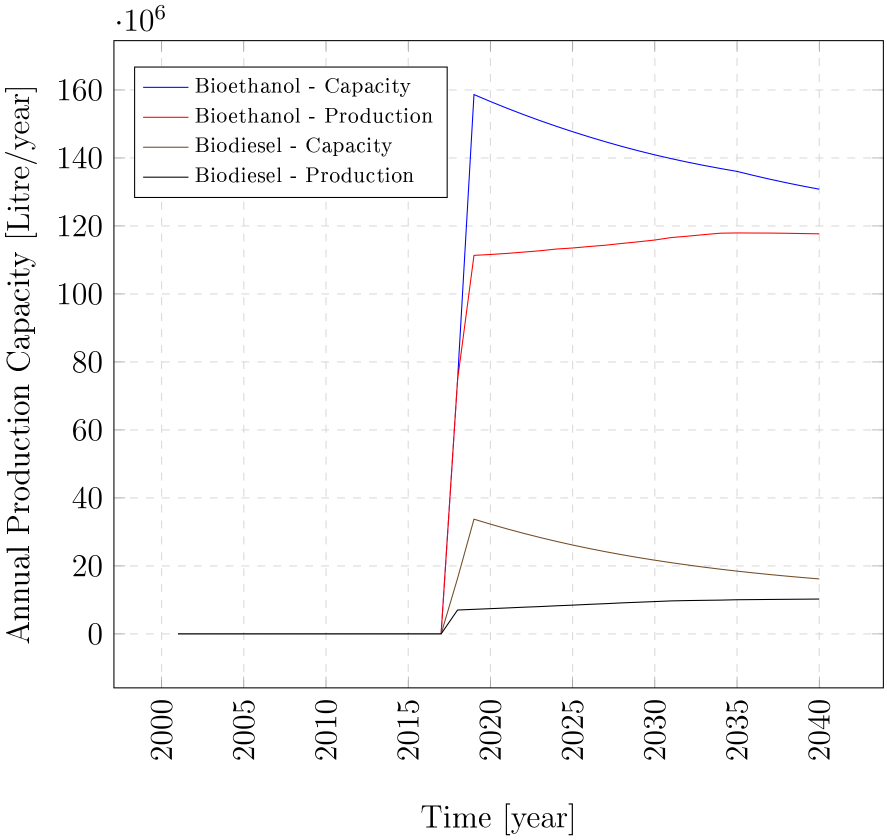

Figure 4.1: Biofuel Capacity and Production

The biodiesel production and capacity simulation shows behaviour similar to that of bioethanol. Figure 4.1 shows the biodiesel capacity drastically exceeding the amount of biodiesel that can be produced with the available feedstock. The biodiesel production volume reaches a maximum of roughly 10 million litres per year, which is a fraction of the demand within the Province. Figure 4.2 indicates the small amount of land allocated towards canola growth for biodiesel, which severely impedes the feasibility of large scale biodiesel production within the Province through the use of canola as feedstock.

By making use of the estimated fuel demand of the Province produced by the Western Cape Province's infrastructure sub-model[2], Figure 4.3 indicates the expected shortage of biofuel in the Province, based on the production outcomes. It is shown that although neither of the production facilities will be operated at full capacity, the bioethanol produced will be more than adequate to meet the bioethanol demand of the Province according to the blending mandate. The same cannot be said for biodiesel, and a major biodiesel shortage is foreseen if the Province is to comply with the blending mandate through local production, using canola as feedstock.

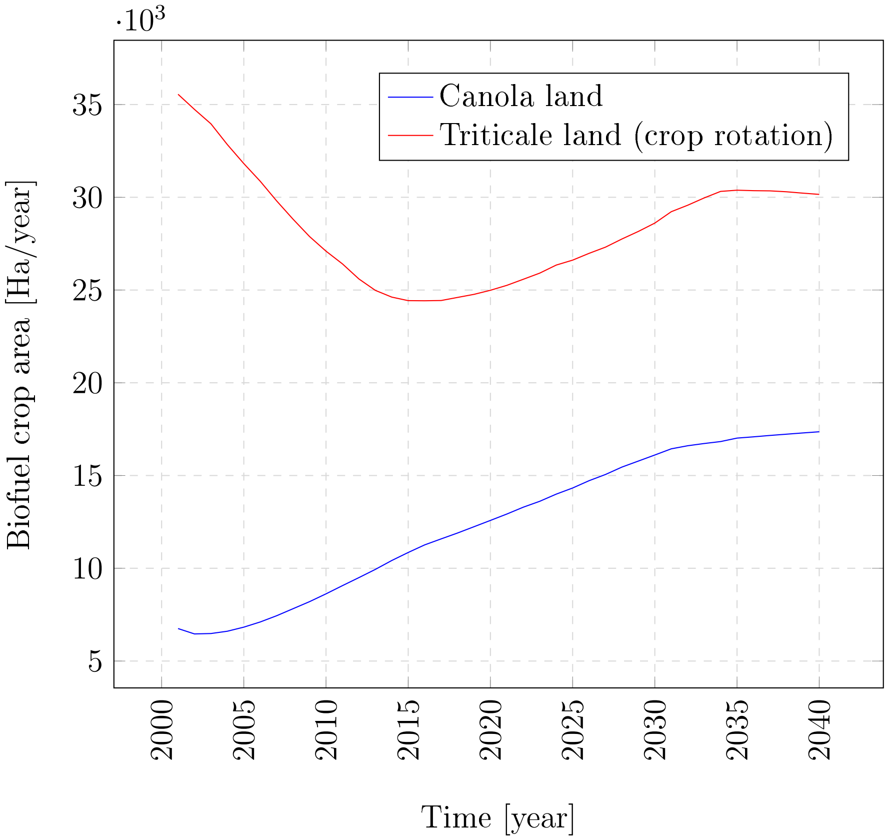

Figure 4.2: Crop production area

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[2] The WeCaGEM model was presented at the 33rd International Conference of the System Dynamics Society held in 2015 at, Cambridge, Massachusetts, USA (Musango *et al.*, 2015).

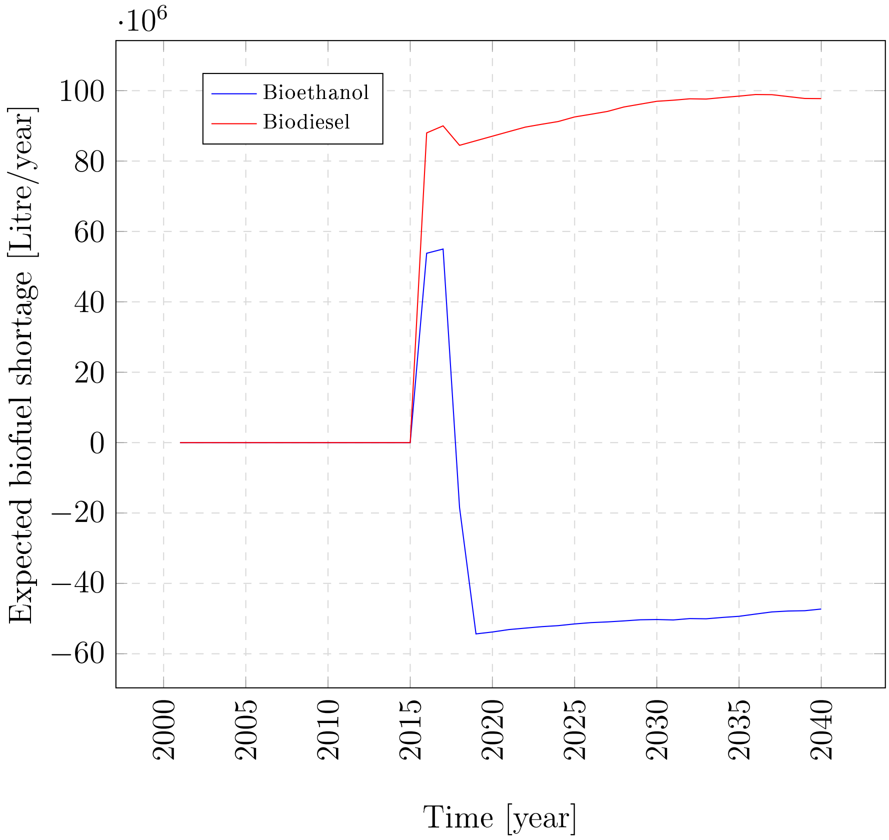

Figure 4.3: Expected biofuel shortage in the Western Cape Province

4.1.2 Biofuel Expenditure

The monetary expenditure to produce biofuels includes operating and capital expenses (in the form of a loan repayment). The constituents of the operating expenses have been identified and discussed previously.

Table 4.1 shows the expected growth of the operating expenses of bioethanol. For simplicity, the values are indicated in 10 year intervals, with the first year of production being 2018. It can be seen how feedstock cost is expected to increase by up to four times over a 20 year period, which has severe impacts on production cost, as feedstock costs make up 60-70% of the total production cost. Water and chemical costs also increase exponentially over the simulated time, while maintenance expenditure remains fixed. The constant value for maintenance is due to the estimation of maintenance as a fixed percentage of capital value. In reality it is however expected that maintenance costs will be lower initially and then exponentially increase as the facility ages. It can however be assumed that the initial overestimation of maintenance fees, will cover the associated costs towards the plants' end of life. Labour costs increase with inflation, as expected, and wages are calculated on the assumption that the plant will operate 24 hours per day for 330 days of the year.

Table 4.1: Bioethanol - Operating Expenditure (R '000 000/year)

	2018	**2028**	**2038**
Feedstock cost	250	637	1 083
Water cost	13	33	55
Chemical Cost	25	86	194
Maintenance Cost			
:LP (Boiler)	14	14	14
:LP (CHP)	43	43	43
Labour	8	20	30
Energy Cost			
:LP (Boiler - Coal)	53	149	284
:LP (Boiler - Biomass)	65	179	335
:LP (CHP - Coal)	107	176	290
:LP (CHP - Biomass)	142	234	385
OPEX			
:LP (Boiler - Coal)	361	935	1 658
:LP (Boiler - Biomass)	373	966	1 709
:LP (CHP - Coal)	444	992	1 693
:LP (CHP - Biomass)	479	1 050	1 788

A comparative evaluation of the different production scenarios shows a notable variation in energy costs as part of the operating expenses. Scenario 1 is the least costly option in terms of energy costs and this is due to the high energy density of coal compared to biomass, meaning that although the cost of biomass is almost half that of coal per ton, much more biomass is needed to provide the same energy. In all of the local production scenarios, making use of coal is a more affordable option, where using biomass is roughly R50- and R95-million per year more expensive than coal for the boiler and CHP options, respectively, in 2038.

The overall OPEX shows the two local production scenarios using coal as combustible to have the lowest operating costs, while scenario 2 and 4 (making use of biomass) are more costly. Scenario 4, having a high combustible demand due to the CHP unit and making use of biomass, has the highest associated cost and will operate at an expected R1.8 billion rand per year in 2038.

The loan repayment towards capital for the bioethanol production facility, using a boiler and including a CHP unit, is R285 million and R880 million per year, respectively. The first instalment is to be paid in 2016 and the last in 2035. Although the initial CAPEX required is R900 million and R2.8 billion for the boiler and CHP bioethanol plants, respectively, these costs are drastically increased due to the interest rate and the 100% debt scenario assumed.

The scale of biodiesel production causes it to have notably lower operational costs, although trends in cost increases are similar to that of bioethanol. The feedstock costs are relatively high in the boiler scenarios (1 and 2), and constitute roughly 80% of the total operating costs, while the feedstock costs in the CHP scenarios (3 and 4) only contribute 30% of the total operational cost. This is due to the large amount of combustible required by the CHP plant, which makes the price effect of feedstock small by comparison. Table 4.2 further shows chemical cost to be a large expense, with the cost of methanol and Potassium Hydroxide reaching R62 million in 2038. Although methanol can be recovered and reused as part of the process, which will reduce costs, it is generally not recommended for a plant of this size due to quality and cost concerns.

Maintenance costs remain constant over the lifetime of the plant and the same assumptions made for bioethanol apply here. A notable difference can be seen in the maintenance costs associated with a boiler facility only when compared to a facility including a CHP unit. This is especially pertinent due to capital costs of a small scale boiler plant compared to a large scale CHP unit. Labour costs vary over time according to production capacity and the inflation rate. It is expected that R9 million will be spent annually on labour in 2038.

When evaluating the energy costs of the local production scenarios, the high energy costs involved with a facility including a CHP plant drastically outweighs the boiler plant's energy cost. Scenario 1 and 2, making use of a boiler only, show similar energy costs, and this is due to the relatively small quantity of combustible required to provide process heat. Using biomass to fuel the boiler is at most R300 000 per year more expensive than coal. When looking at the larger scheme of operational expenditure, this difference becomes insignificant and the OPEX of both local scenarios relying on a boiler and grid electricity for energy supply are equal. The energy costs for the CHP options (scenario 3 and 4) are identical to that of bioethanol production because the size of the CHP plant envisaged is the same for both production facilities. The OPEX of the CHP scenarios are more than double that of the boiler options, with the expected operating costs reaching R706 million in 2038 for the CHP with biomass scenario. The CHP with coal scenario will operate at roughly R100 million less than its biomass counterpart in 2038.

Table 4.2: Biodiesel - Operating Expenditure (R '000 000/year)

	2018	**2028**	**2038**
Feedstock cost	60	128	235
Water cost	2	3	5
Chemical Cost	8	27	62
Maintenance Cost			
:LP (Boiler)	3	3	3
:LP (CHP)	32	32	32
Labour	4	7	9
Energy Cost			
:LP (Boiler - Coal)	2	5	12
:LP (Boiler - Biomass)	2	6	13
:LP (CHP - Coal)	107	176	290
:LP (CHP - Biomass)	142	234	385
OPEX			
:LP (Boiler - Coal)	75	161	304
:LP (Boiler - Biomass)	75	161	304
:LP (CHP - Coal)	209	361	611
:LP (CHP - Biomass)	244	419	706

The biodiesel capital repayment for the conventional plant, making use of the boiler, is R64 million per year, while the production plant including the CHP unit will have annual repayments of R670 million until 2035. In a similar fashion to bioethanol production, the expenses associated with capital are severely inflated due to the interest rate and the 100:0 debt equity ratio assumption.

4.1.3 Operational Finances

The operational costs were largely driven by annual increases, where historical costs indicate that most of the operational costs increase at a rate higher than inflation. The operational costs stay the same for all of the scenarios. Table 4.3 shows how the prices of the various operational factors are expected to increase over the simulation time. It is important to note that the annual price increase might give an overestimation of costs, which could be improved by taking the effect of supply and demand into account, but would require extensive additional models. The lack of supply and demand feedback effects are a limiting factor, but it can be reasonably assumed that the supply and demand effects of regional production (of this scale) on national commodity prices and markets, will be negligible and were thus excluded from the scope of the study.

Biofuel feedcrop is expected to increase at 5% per annum, and is further influenced by a lookup of feedstock demand and supply, limited and contained within the biofuel market. Due to the low volumes or complete lack of triticale production in SA and especially the Western Cape Province, the market value of triticale is uncertain, and is currently expected to sell between R1500-R2000. The market value of triticale is estimated to reach R4319 per ton in 2038. The low cost of triticale is one of the key factors that lead to the strong business case for bioethanol production using triticale as a feedstock.

Canola cost also increases at 5% per year, but is relatively expensive when compared to triticale. This is due to the low density and agricultural yield of canola. Table 4.3 indicates how the price of canola is expected to grow, reaching R10 491 per ton in 2038. The simplified simulation of canola price was found to correlate well (deviation of less than 10%) with the values produced by the agricultural[3] model. The high initial and expected escalation of biodiesel feedstock cost is expected to hamper biodiesel production if no other factors are incorporated to strengthen the business case for biodiesel production.

The technical and administrative wages are initially defined according to the average wages witnessed in SA and then grown at the current inflation rate of 4.6%. This sees the hourly wage increase from R24 per hour in 2018 to R60 per hour in 2038. The management salary was initially defined at R250 000 per year in 2001, and also grown at inflation. Table 4.3 shows how the annual salary of a manager is expected to increase to R1.3 million in 2038.

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[3] The WeCaGEM model was presented at the 33rd International Conference of the System Dynamics Society held in 2015 at, Cambridge, Massachusetts, USA (Musango *et al.*, 2015).

The water unit cost and combustible cost increase at 5% per year and the expected price escalation is indicated in the table. Water and coal costs correlate well with current expected values, while biomass is difficult to validate, based on the fact that the biomass market is not officially or centrally governed. The biomass price therefore depends greatly on the source of the biomass. It was mentioned earlier that the price of biomass could be drastically decreased if it were to form part of the alien invasive land clearing scheme.

Electricity and chemical costs increase at an expected 8% per year, although the electricity price has seen even higher increase rates in recent years due to the energy crises. Table 4.3 shows the cost of industrial electricity to reach R2.21 per kWh in 2038. The model only considers the chemicals that are expected to make up the majority of production costs and it can also be seen how these four main chemicals are expected to drastically increase in cost over the simulation time.

The last operational driver (indicated in Table 4.3) greatly influencing the business case of biofuel production is the market value of the by-products produced. The market price of DDGS, as part of the bioethanol value chain, is mainly determined by the production process used, as different techniques will produce by-products varying in quality. This study assumed the pre-fractionation production process, which will deliver DDGS of a higher quality, where a current market price of up to R7000 per ton has been estimated. However, uncertainties regarding the market response to an influx of high quality animal feed, lead to a conservative estimate of the market price that sees DDGS increasing from roughly R2000 per ton in 2018 to R9578 per ton in 2038. The canola oilcake produced as a by-product of biodiesel production can also vary in price, depending on the fat content. The simulation shows the price of canola oilcake increasing from R2640 per ton in 2018 to R13 026 per ton in 2038.

Figure 4.4 shows how the value of assets decrease according to straight-line depreciation as stipulated in the National Biofuel Regulatory Framework. It can be seen how the value of the assets in the CHP options for bioethanol and biodiesel production are much higher than that of the boiler options. The value of the assets decrease on straight-line basis over the expected lifetime of 20 years. This decrease in the value of assets will influence the ROA calculation and the tax owed.

4.1.4 Profitability

In order to evaluate the feasibility of biofuel production, the profitability and return on investment is calculated and considered. The trends in simulation outcome for bioethanol and biodiesel are very different and confirm the expectations based on previous studies.

Figure 4.5 shows the ROA of the four local bioethanol production scenarios. The two boiler scenarios have a notably higher ROA when compared to the CHP scenarios, which is due to the value of the assets as explained in the previous section. The CHP scenarios require an investment more than three times bigger than that of the boiler options, implying that revenues from surplus electricity sales as a product of the CHP scenarios will have to increase overall revenue by more than three times in order to achieve a ROA comparable to that of the boiler options. By evaluating the return on investment of bioethanol production at the hand operating ROA of the four local production scenarios, it is evident that the boiler

Table 4.3: Operational Costs

	Units	**2018**	**2028**	**2038**
Biofuel Crop feedstock cost				
:Bioethanol - Triticale	Rand/ton	1 571	2 604	4 319
:Biodiesel - Canola	Rand/ton	3 841	6 343	10 491
Technical & Administrative staff wages	Rand/person/hour	24	38	60
Management salary	Rand/person/year	545 847	864 092	1 368 000
Water unit cost	Rand/kilolitre	6.54	10.78	17.76
Combustable cost				
:Biomass	Rand/ton	385	635	1 046
:Coal	Rand/ton	650	1 018	1 763
Electricity Cost	Rand/kWh	0.45	1.00	2.21
Chemical				
:Bioethanol - Yeast	Rand/kg	175.12	388.97	863.94
:Bioethanol - Enzyme	Rand/kg	112.61	250.11	555.53
:Biodiesel - Methanol	Rand/kg	4.66	10.35	22.99
:Biodiesel - Catalyst	Rand/kg	8.54	18.97	42.14
By-product selling price				
: Bioethanol - DDGS	Rand/ton	1 942	4 312	9 578
: Biodiesel - Canola Oilcake	Rand/ton	2 640	5 865	13 026

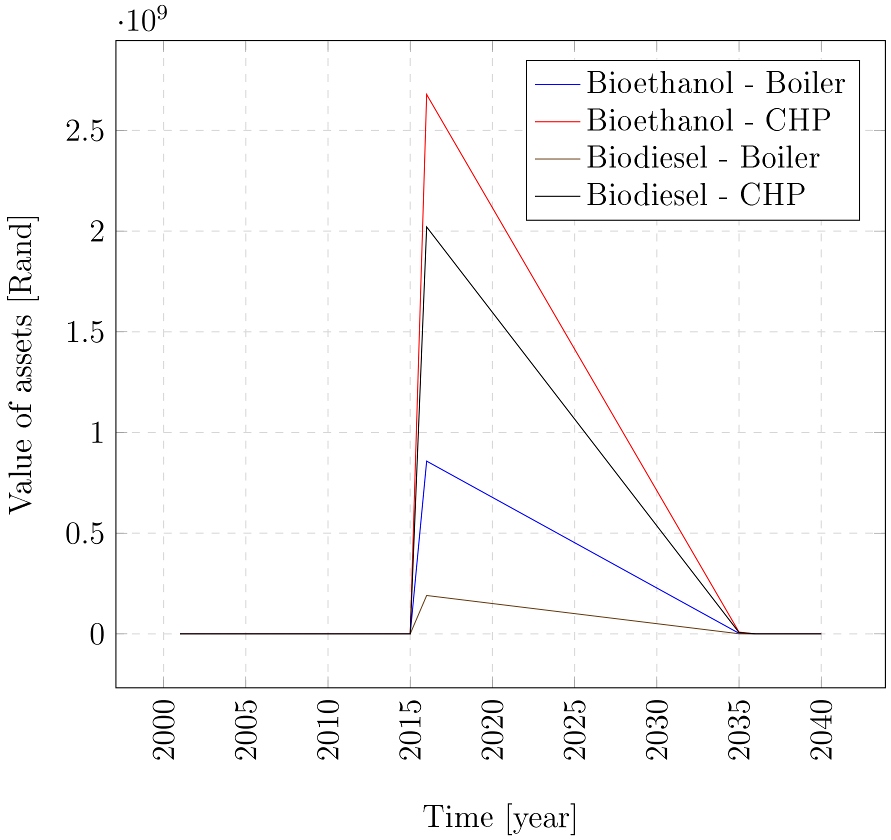

Figure 4.4: Value of Assets

using coal as energy source will be the most rewarding scenario, followed by the boiler using biomass and the CHP option using biomass, while the CHP option using coal is the least rewarding.

Bioethanol requires no subsidy to achieve the guaranteed 15% ROA in any of the scenarios, except in the first year of production (2018), for the case of local production with the CHP plant making use of coal as combustion material. This is due to the high value of assets in the first year and the relatively low value of the electricity sales price compared to the price of electricity produced by renewable sources (biomass). ROA is only indicated up to 2030, as the ROA becomes unrealistically high when the value of assets tend to zero.

The unrealistic values produced by the ROA calculation towards the end of the biofuel plants' lifetime, due to the low value of assets determined according to the National Biofuel Regulatory Framework, raised some concern in terms of us-

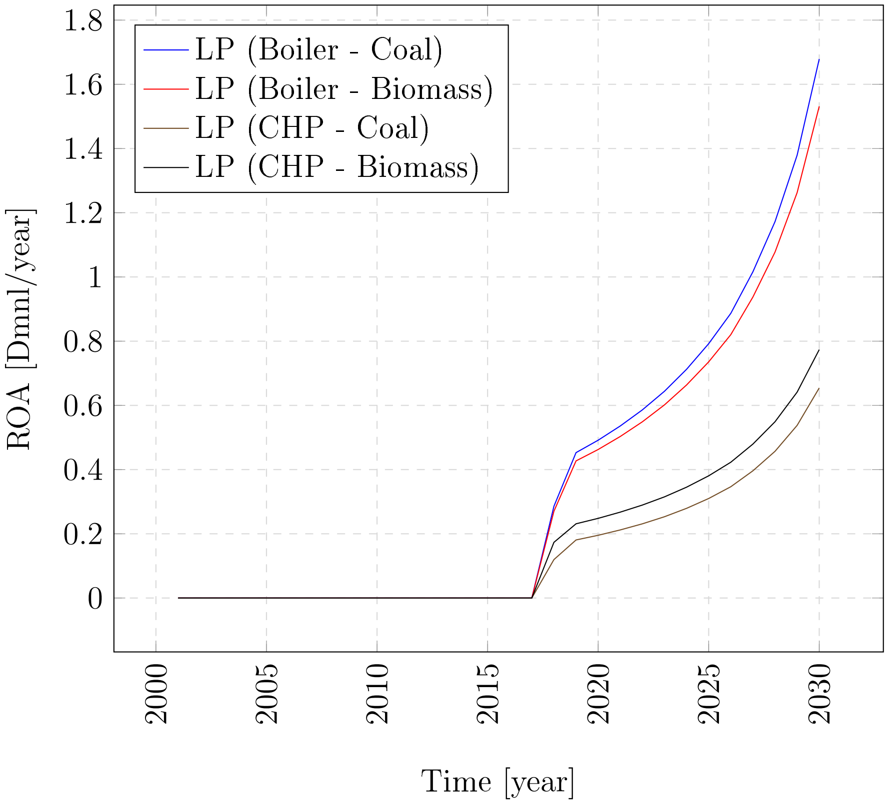

Figure 4.5: Bioethanol - ROA

ing ROA solely to evaluate the business case of biofuel production. IRR is thus also calculated and indicated in Figure 4.6 to evaluate the financial feasibility of bioethanol production in the Western Cape Province.

The IRR simulation indicates the financial feasibility or earnings in the same order as ROA. The IRR is initially negative due to the high investment requirement, but shows positive IRR's for the boiler scenarios by 2021. Positive IRR values are shown for the CHP scenarios by 2025. Scenario 1 looks to be the most rewarding alternative, with an expected IRR of 25% over its operational lifetime. Scenario 2 follows with an IRR of 23%, while the CHP options in scenario 3 and 4 show an IRR of 14% and 11%, respectively.

The returns and profits for biodiesel do not follow the same trends witnessed in bioethanol production. Scenario 1 and 2, making use of a boiler and grid electricity, have nearly identical values and show a negative ROA over the entire lifespan of

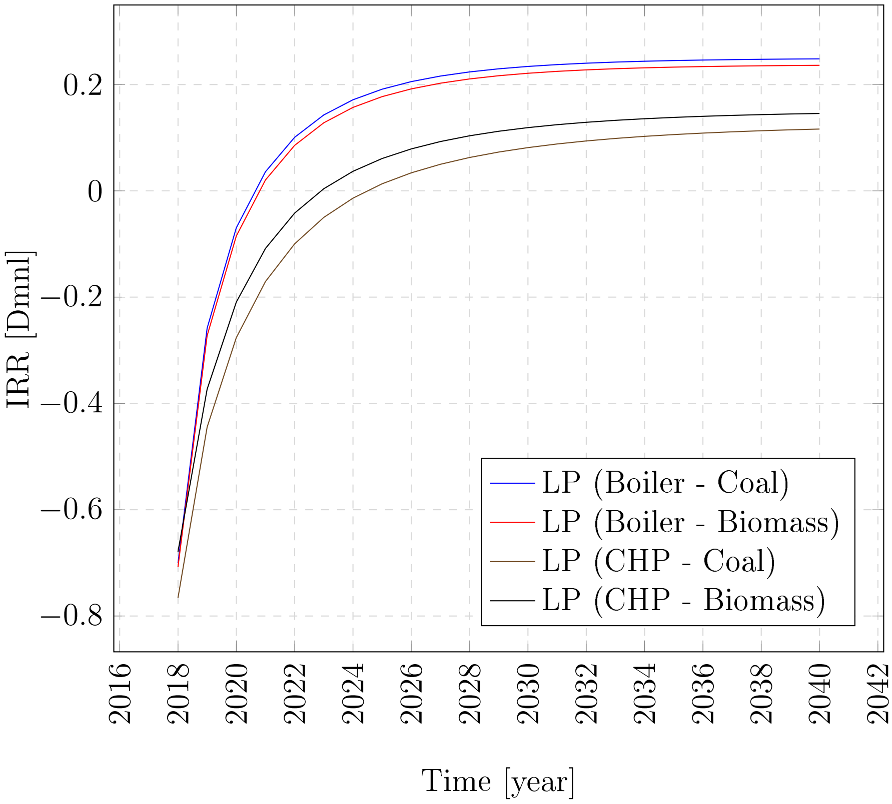

Figure 4.6: Bioethanol - IRR

the project. This is due to the high investment cost relative to the low volumes of biofuel produced and sold, which causes the ratio of revenue to investment to be extremely low. The CHP scenario using coal (scenario 3) produces a small positive ROA until 2023 and then turns negative, showing that this scenario is not a feasible alternative for biodiesel production. The fourth scenario where biomass is used in the CHP plant, does however return a constantly positive ROA, which peaks at 12%. The biomass option returns a positive ROA, due to the high anticipated cost that will be obtained for the sales of surplus electricity cost that is sourced from renewable energy sources. If electricity from the CHP plant is not sold to the grid at the planned R1.40 per kWh, the business case for biodiesel is not a compelling one. Noting that none of the scenarios for biodiesel production deliver an ROA of more than 15%, a subsidy is required to guarantee this return.

Figure 4.8 shows the subsidy required per litre to attain the guaranteed 15% ROA. The results are counter-intuitive, as it shows a much higher subsidy required for scenario 3 and 4, which had higher ROA values than scenario 1 and 2. This is

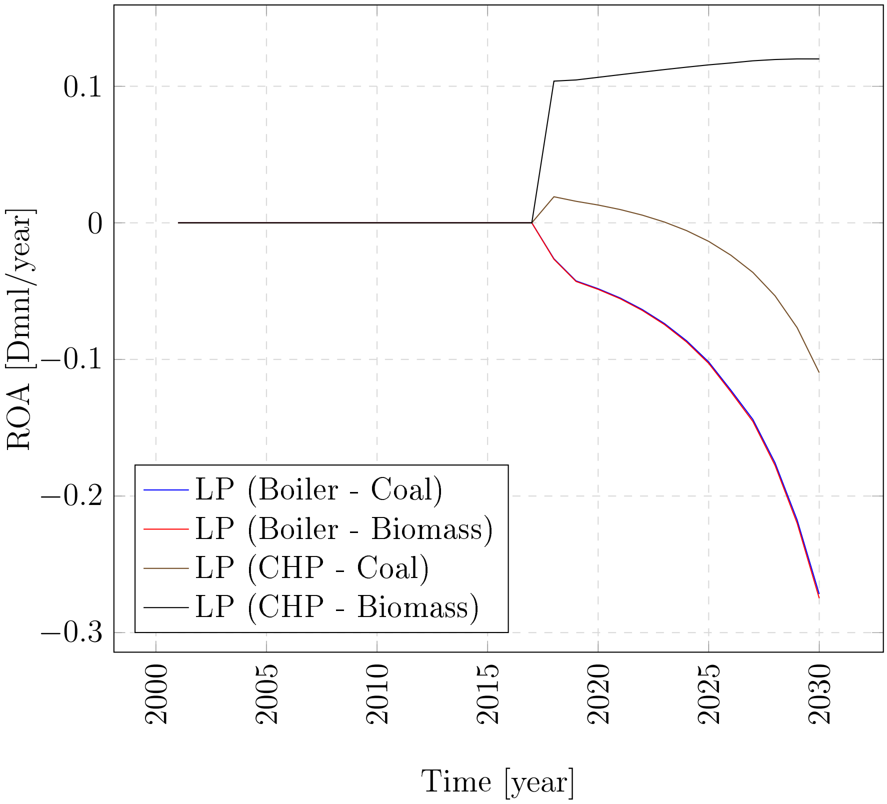

Figure 4.7: Biodiesel - ROA

however due to the much higher asset values of a CHP facility, which thus requires a much larger subsidy to achieve an increase in ROA. For the CHP scenarios, it was found that a maximum subsidy of R33 and R12 is required in the first year of operation for the coal and biomass fired options, respectively. Although the subsidies required decrease quickly after the first year, they are still impractically high over the project's lifetime and unlikely to lead to a rewarding investment for any of the stakeholders. Scenarios 1 and 2 require a much lower subsidy of between R4.30 and R1.70 per litre of biodiesel sold. Once again, it is important to investigate the IRR to determine the overall financial feasibility of the project.

The IRR function in Vensim® will not return an IRR value if, the IRR value is larger than 1 or smaller than -1, or if the cash flow changes from positive to negative or vice versa (where multiple IRR solutions could be possible). Figure 4.9 only shows realistic IRR values for the local production scenarios (3 and 4) incorporating the CHP facility. The IRR values for scenario 1 and 2 are very large negative values (falling outside the bounds permitted in Vensim®). Scenario 3 has negative

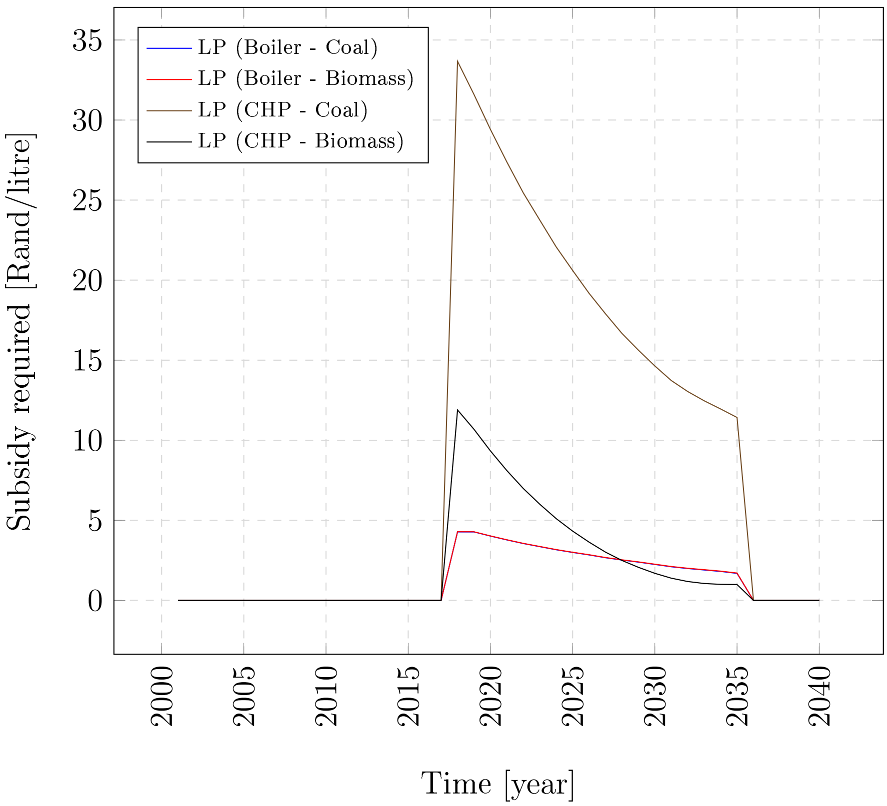

Figure 4.8: Biodiesel - Subsidy required

IRR values until 2024, where the cash flow changes from positive to negative, resulting in multiple IRR solutions (thus not displayed in simulation). Scenario 4 has constant negative IRR values over the entire lifespan of the project. This indicates that a biodiesel production facility in the Western Cape Province, under the current assumptions, would not make financial sense, even with the subsidies proposed.

4.1.5 Bottom Line Cost

The bottom line costs refer to the overall cost involved if the Western Cape Province were to form part of the blending mandate, and incorporates scenario 5 and 6, where the alternative of purchasing biofuel from existing biofuel plants is considered.

Figure 4.10 graphically presents the various local and non-local production alternatives. As expected at the hand of the profitability discussion, scenario 1 and 2

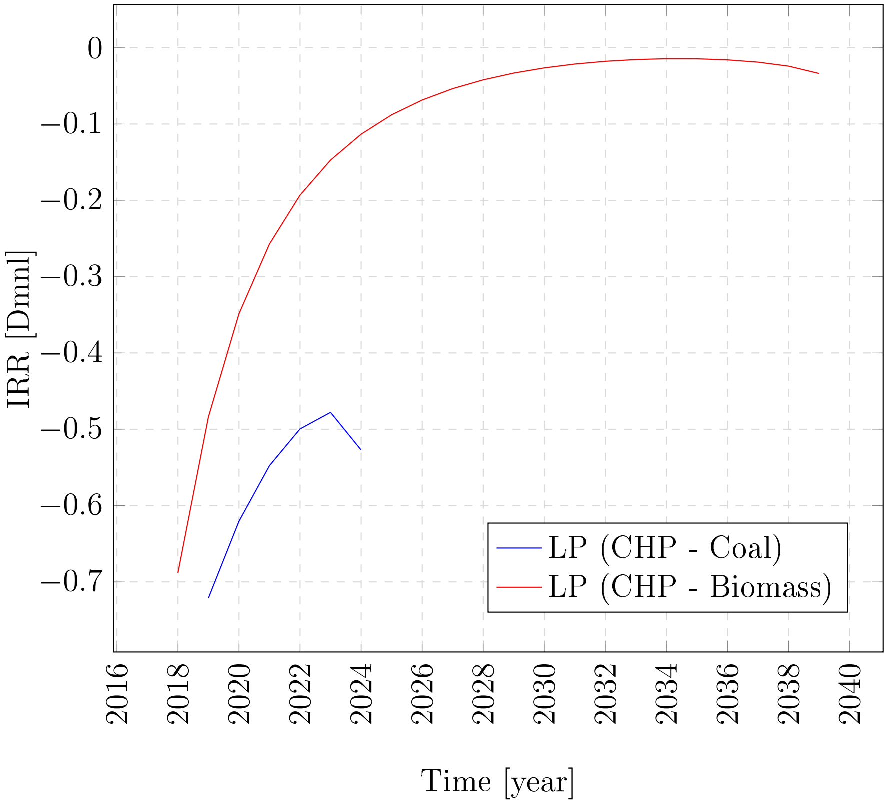

Figure 4.9: Biodiesel - IRR

have the lowest bottom line cost to the Province, peaking at R800 million in 2018, after which it slowly decreases as the revenue starts outweighing the expenditure. A drastic decrease in expected bottom line costs occurs in 2035, once the capital loan has been repaid. Scenario 3 and 4 follow a similar trend, but have a much higher bottom line cost, where scenario 3 reaches a maximum cost of R10 billion in 2035 before it starts decreasing. Crucial insight is gained by seeing that the NLP scenarios (5 and 6) have identical bottom line costs, as the production technique does not influence the BFP at which the bioethanol is bought from other production plants.

Further, it is shown how the NLP scenario initially has lower associated costs, but exceeds the LP scenarios 1 and 2 in 2019. The NLP scenarios exceed scenario 3 and 4 in 2024 and 2025 ,respectively, and are expected to cost notably more than any of the local production scenarios. This was expected as, the NLP scenarios are based on a continued expense, while the local production scenarios will start bringing revenue into the Province. Evaluating whether bioethanol should be

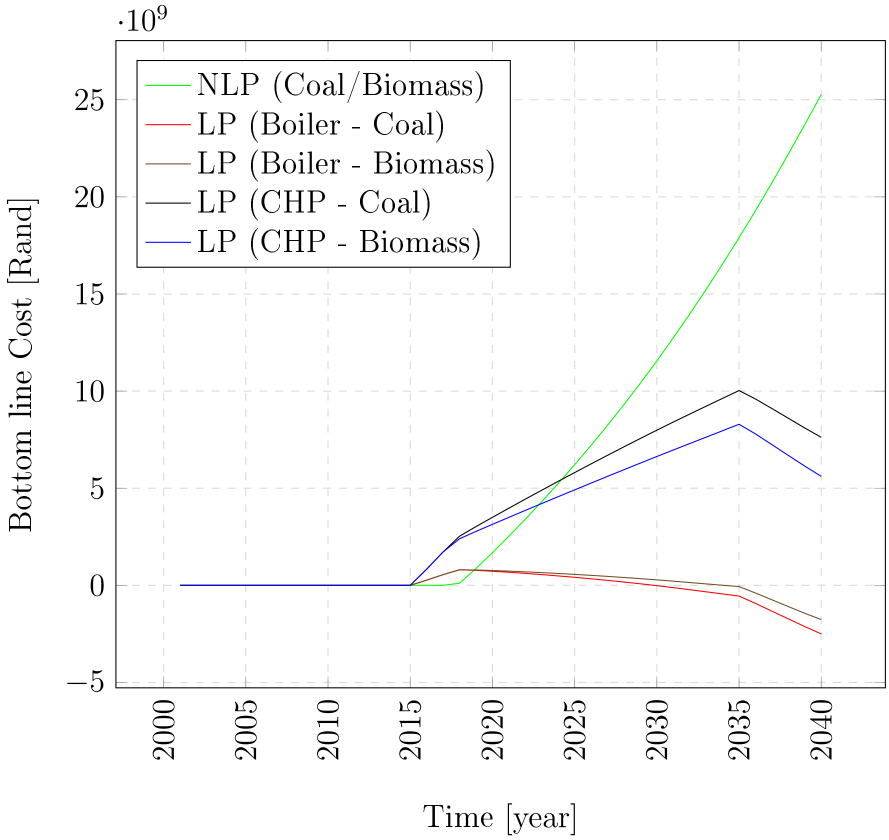

Figure 4.10: Bioethanol - Bottom Line Cost

produced locally or bought from existing plants, purely at the hand of bottom line cost implications for the Province, indicates that bioethanol should be locally produced making use of a coal boiler. A close second alternative to this option is local production scenario 2, making use of biomass, costing approximately R740 million more than the cheapest option by 2040. The figure also indicates how scenarios 1 and 2 cause a nett profit/financial income for the Province by 2030-2035, which can greatly influence the GDP and other financial indicators.

Figure 4.11 shows the bottom line cost of complying with the biodiesel blending mandate. It is evident that the local production scenarios incorporating a CHP system will be the most costly alternative, while the non-local production scenario remains the least costly until 2036, when it becomes marginally more expensive than scenarios 1 and 2. These bottom line costs, combined with the weak business case and financial returns of biodiesel production in the Western Cape Province suggest that it would be more beneficial to purchase biodiesel from

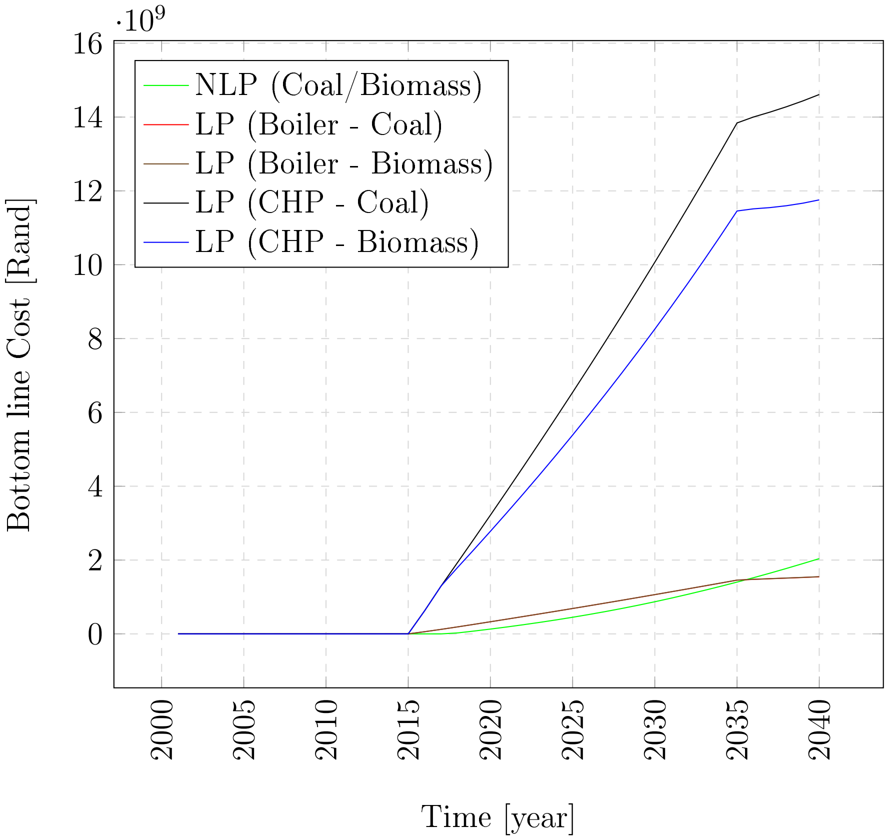

Figure 4.11: Biodiesel - Bottom Line Cost

existing biodiesel producers.

4.1.6 Employment

The additional jobs created by the agricultural sector are estimated at 2080 jobs, and the production of bioethanol will contribute between 30 and 60 additional jobs, depending on the production capacity, where the expected average is estimated at 55 additional jobs.

The employment creation of the biodiesel sector does not consider the agricultural sector, as the feedstock is a portion of canola that would have been produced regardless of the biofuel market. The operational employment requirement is expected to contribute between 10 and 15 additional jobs.

4.1.7 Emissions

The boundaries and assumptions under which emissions are evaluated have been established earlier and as expected, the emissions are dependent on the combustible used for process energy. Figure 4.12 shows how local production and non-local production scenarios (1, 3, 5) using coal, have higher expected emissions than the scenarios using biomass, while the non-local production scenario 5 has the highest emissions, due to the added emissions caused by transportation of the bioethanol to the Western Cape Province. The CHP and boiler scenarios are shown to have the same emission factors, as the emissions contributed to surplus electricity generation are not included.

Producing bioethanol by using biomass as process energy supply delivers the lowest overall emissions. The emissions produced by the facility when utilising biomass are 63% less than when coal is used, indicating that significant environmental benefits are offered through the use of biomass as energy supply.

In the production of biodiesel, the different scenarios deliver comparable emission levels due to the small scale of the operation. Figure 4.13 indicates non-local production to have the highest emission levels, due to the added emissions caused by transportation of the biodiesel. There is only a 5% reduction in emissions when making use of biomass for local production when compared to non-local production using coal, indicating a relatively small increase in environmental impact through the purchasing of biodiesel from established facilities.

4.2 Simulation Summary and Recommendations

Upon reviewing the various results produced by all of the sub-models for each scenario, it is possible to conclude and summarise the key findings produced by the simulation based on the current assumptions. It is important to note that although every attempt was made to achieve accuracy in the model parameters and outputs, the assumptions made due to the uncertainty of the pricing structures and policies will have an effect on the output values. The focus is thus placed on the system behaviours and trends witnessed in the simulation as the most important decision-making factors.

Bioethanol
A strong business case for bioethanol production in the Western Cape Province exists. A bioethanol plant to be completed in 2018 with a maximum production capacity of 160 million litres per year is feasible, although full production capacity

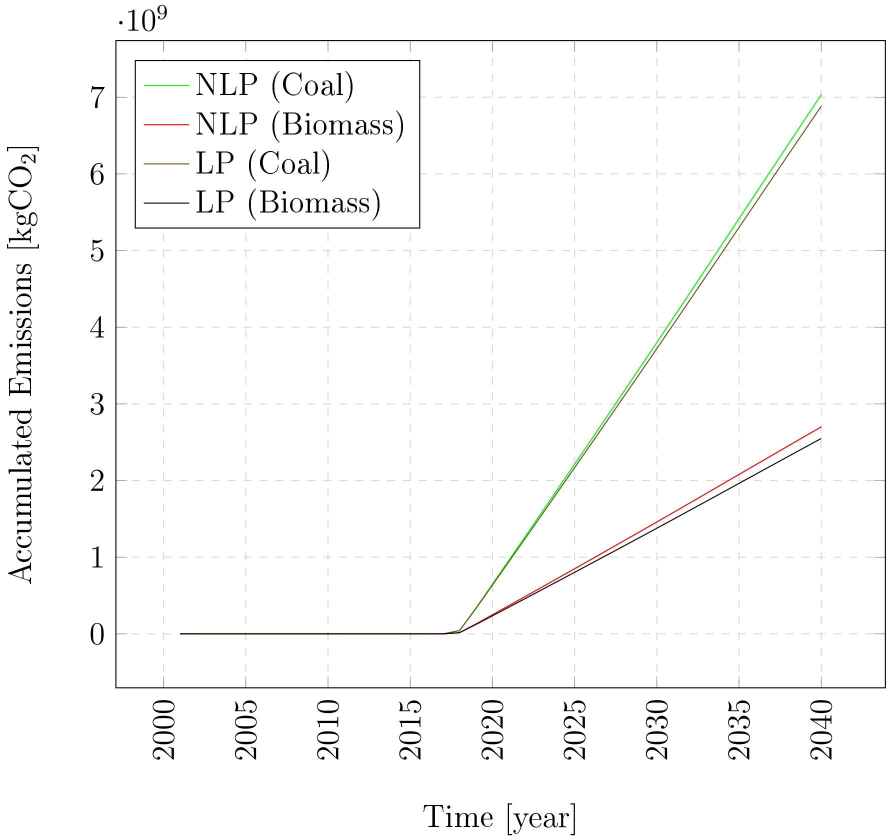

Figure 4.12: Bioethanol - Emissions

is not utilised under the current feedstock availability expectations, which sees production capacity limited to roughly 120 million litres per annum. A production plant using grid provided electricity and a boiler will cost R900 million to construct, while a facility including a CHP unit will cost R2.8 billion. Operating expenses associated with the respective production facilities differ and are also influenced by the type of combustible used. Operating expenses are expected to grow from an estimated R361-R480 million in 2018 to R1.6-R1.7 billion in 2038.

No subsidy is required in any of the production scenarios to reach the guaranteed 15% ROA. Further evaluating the financial viability of bioethanol production in the Western Cape Province, it was found that a production facility utilising grid electricity and a coal fired boiler will produce the highest IRR at 25%, while the use of biomass in the same facility delivers an IRR of 23%. The CHP options are not as lucrative with estimated IRR's of 11-14%.

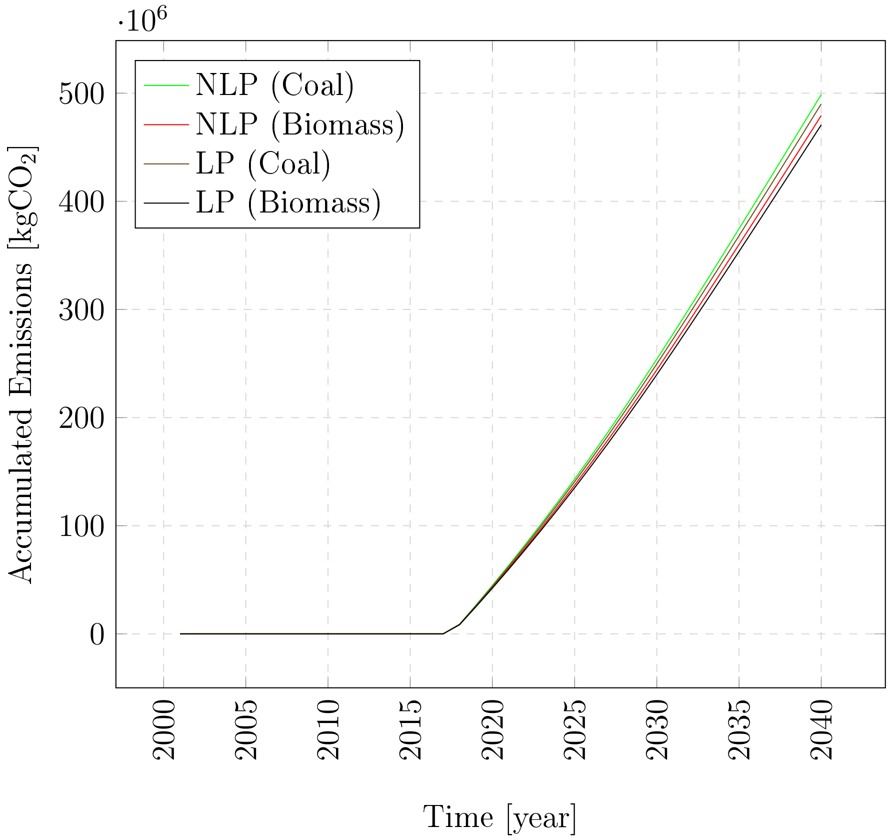

Figure 4.13: Biodiesel - Emissions

When considering the bottom line costs of the alternative of purchasing bioethanol from an existing plant elsewhere in the country, it was strongly indicated that local production (boiler fuelled by coal) would be the least costly. Although the local production scenario making use of biomass is more costly than the coal fired option, it would still be more affordable than purchasing bioethanol in the long run. Of all the scenarios that would see the Province forming part of the mandatory blending scheme, purchasing and transporting such a large amount of bioethanol from elsewhere would have the largest financial impact. Over and above the cost implications, the non-local production scenarios would not be capable of generating the estimated 2135 additional jobs, which may be possible through local bioethanol production scenarios. Lastly, the emissions produced by non-local production exceed that of the associated local production scenarios, while a locally producing facility utilising biomass for process energy is expected to deliver the lowest amount of emissions.

Recommendation:

Local production scenario 2 (Boiler - Biomass) is recommended, as an IRR of 23% is achieved, while emissions are reduced by 63% compared to the coal fired counterpart.

Further recommendations to strengthen the business case for local bioethanol production, are discussed in the final chapter and consider:

i. Improving feedstock availability;

ii. Reducing capital costs through alternative financing options; and

iii. Incorporating bioethanol production as part of an alien invasive land clearing scheme.

Biodiesel

Local biodiesel production does not provide a compelling business case under the current assumptions and parameters. Simulation results indicated that limited feedstock availability in the Province restricts the scale of biodiesel production to a level that would not be financially feasible. An estimated 10 million litres of biodiesel can be produced annually if 25% of canola harvested in the Province is directed towards biodiesel production. Roughly 10 times this amount is required to meet the demand of biodiesel in the Western Cape Province under the blending regulations.

A biodiesel facility capable of producing 35 million litres per annum is expected to cost R200 million when using a boiler and R2.1 billion when using a CHP unit. Operating costs vary drastically and a very large subsidy is required to deliver the guaranteed ROA for the facility including a CHP unit. The local production scenarios without the CHP unit required the lowest subsidy of R4.30 per litre. However, even if this subsidy is considered, the IRR of biodiesel production is too low to be a feasible alternative.

The bottom line cost implications of complying with the blending mandate supports the notion that local biodiesel production is not financially feasible. The bottom line cost was the lowest for non-local production, although closely followed by local production scenarios not incorporating a CHP unit. By producing biodiesel locally, an estimated 15 additional jobs will be created and emissions are reduced by 5% compared to non-local production. However, these positive contributions do not justify the financial burden that accompanies local biodiesel production.

Recommendation:

It is advised that biodiesel is not produced locally within the current capacity and feedstock assumptions, as it results in a scale of production which is not financially feasible. Biodiesel should be bought from an existing plant, if necessary, or sourced from small scale independent biodiesel producers within the Province.

Further recommendations as part of incorporating biodiesel into the Western Cape Province's transition to a green economy include:

i. Investigating other feedstock options for biodiesel production;

ii. Encouraging independent small scale biodiesel production; and

iii. Investigating the biodiesel value stream to improve the business case.

Chapter 5

Conclusion

The preceding chapters explored the biofuel production potential of the Western Cape Province by identifying the main drivers and constraints to the industry. System dynamics was used to simulate a variety of scenarios in order to indicate the outcomes of providing the Province with biofuel under different assumptions. The following section provides insights and recommendations at the hand of the research and modelling outcomes and findings. Concluding remarks on the implications and expectations of meeting the mandatory biofuel blending policy within the Western Cape Province are also provided and discussed.

5.1 Simulation Implications and Recommendations

The simulation summary and recommendations in Section 4.2 provides the most important findings of the various scenarios that were investigated. Recommendations are made to inform stakeholders of possible intervention points in key strategic areas, where intervention could strengthen the business case and feasibility of meeting the Province's biofuel demands. Recommendations are based on the factors that constrain the feasibility of biofuel production under the assumptions of the simulation. Although the financial feasibility of biofuels is largely dependant on the BFP and feedstock price, the recommendations made are aimed at the drivers that are not exogenously determined.

5.1.1 Bioethanol

In order to successfully incorporate bioethanol as part of the fuel supply mix in the Western Cape Province, some of the key drivers within the industry have to be strategically managed.

One of the major constraints in bioethanol production is the expected feedstock availability. The amount of feedstock is dependant on land availability and farmer uptake of triticale cultivation. The first recommendation to strengthen the business case for bioethanol production is thus to **increase the amount of triticale feedstock** available. This could be facilitated by engaging with farmers and stakeholders to establish the amount of under utilised or uncultivated land, which could be allocated to triticale cultivation. However, this is unlikely to be accomplished without providing an incentive to farmers to incorporate triticale as part of their crop cycle.

If farmers do not actively take part in the biofuel production sector, consideration should be given to provide farmers with financial support (possibly in the form of a subsidy) to ensure a market value for triticale, which is at least equal to that of B3 grade wheat. However, the current grain pricing structure could be adequate incentive for farmers to adopt growing triticale, as it will be used locally, meaning that farmers do not have to pay the roughly R600.00 transport differential penalty on the grain market values as determined in Johannesburg. In addition, triticale growth could be beneficial to farmers, because it requires a much lower input cost due to its ability to grow in marginal soil and its high tolerance to drought.

A second recommendation to ensure adequate feedstock availability would be to incorporate triticale growth as part of a low-technology, rural community development and upliftment programme. The programme should be focussed on creating employment and generating revenue for rural communities by setting up small scale dedicated triticale farms. The programme will require investment from the National and Western Cape Governments, in terms of purchasing marginal land in close proximity to rural communities and subsequently allocating responsibility of the said land and farming activities to community members. The members will have to receive basic education and attend workshops to ensure that they have adequate knowledge of the agricultural processes (with particular focus on triticale).

A contract stipulating the expected yield (based on soil properties and land area) should be entered into by the biofuel producer and the newly established farming community. By having the contract in place and a dedicated person (who is well educated in farming practises) acting as a consultant to rural farmers, the biofuel producers can ensure that consistent triticale volumes are produced and delivered yearly. This programme could form part of the Land Redistribution for Agricultural Development (LRAD) programme (South African Government, 2015). The LRAD programme stipulates the criteria for qualifying entities to guide a productive farming community, which can further be ensured through the collaborative effort between established farmers, local and national government and the bioethanol producer. Through the use of this programme, the bioethanol producer would also meet one of the qualifying criteria as set by the blending policy, which stipulates that at least 10% of the bioethanol feedstock should be sourced from emerging or historically disadvantaged farmers (Department of Energy, 2014).

The bioethanol producer would thus be involved in the bioethanol feedstock or agriculture sector, which provides a unique opportunity to have some form of input and management into the sector. The bioethanol producer would be able to ensure that the value chain remains sustainable and that the feedstock purchase price remains in a region that would still provide the expected profits and returns for all parties involved.

The second key intervention point would be to **reduce or manage capital expenditure**. It is expected that the ultimate cost of the project would be drastically reduced if the debt:equity ratio is adjusted to 70:30 or even 60:40, as the current assumption of 100:0 results in exorbitant financing costs. In order to achieve a higher equity share, identification of investors and proving a strong business case for bioethanol production would be of cardinal importance. It is envisaged that the project will form part of a collaborative scheme that will see government and local and international corporations having shared interest in the project.

The United Nations Department of Economic and Social Affairs (UN DESA) appointed an intergovernmental committee of experts to develop a report proposing effective sustainable development financing strategies. One of the main concepts involve the establishment of Public-Private Partnerships (PPP) and the key points identified by the working group supports the findings and recommendations for biofuel production in the Western Cape Province as follows (UNTT Working Group on Sustainable Development Financing, 2015):

- Private and public financing from domestic and international sources are necessary and they should be seen as compliments rather than substitutes;
- Private financing cooperatives are focused on financial incentives and it is thus important to build a domestic investor base with long-term investment horizons to successfully deal with the misaligned short-term incentives;

- Public financing should primarily be aimed at reducing poverty and uplifting communities; and
- Policies to facilitate investment should take a multi-dimensional approach to include:
    - reducing risks by creating an enabling environment;
    - sharing risks by using public funds to access private resources; and
    - reducing short-term orientated behaviour by restructuring incentive programmes.

The third recommendation also relates to cost management and entails **reducing operational energy costs by sourcing biomass through an invasive alien species land clearing scheme**. A number of programmes (i.e. Working for Water, Agulhas Biodiversity Initiative, etc.) are in operation, and they aim to remove the invasive plant species. The invasive plant species have no natural predators and are known to grow at rates much higher than that of indigenous plant species, resulting in the invasion and deterioration of indigenous ecosystems. Woody biomass species like Port Jackson, Black Wattle and Rooikrans have an especially significant impact on water reserves. By establishing a team that could work in cooperation with the invasive alien land clearing schemes, bioethanol producers will be improving the state of the Western Cape Province's ecosystem. In addition, the invasive land clearing schemes will also be contributing to employment creation. These initiatives will also give producers access to large amounts of woody biomass to use for process energy, at a reduced cost.

The **location of the of the bioethanol production plant is a major consideration**, as this is key to optimising the bioethanol supply chain of the Western Cape Province. The bioethanol production plant must ideally be located in close proximity to the agricultural areas where the triticale will be sourced, as well as where the biomass will be sourced (the time horizon of the operation and the density or availability of biomass should be kept in mind). Lastly, the plant should be located in close proximity to fuel depots (refer to Figure 3.1) to minimise transportation costs and ensure responsiveness to fluctuating demand.

Establishing and managing a bioethanol production facility will be a multi-dimensional and cross-disciplinary task that will constantly find itself at the centre of a number of interacting sectors and industries. Noting that the bioethanol sector forms part of a complex system, the above mentioned recommendations provide insight into key strategic areas that are of concern to stakeholders.

5.1.2 Biodiesel

Findings, according to the model output, show that biodiesel production on a medium scale (35 million litres per annum) in the Western Cape Province would not be financially feasible. The emissions savings and employment creation potential is further not substantial enough to justify the establishment of a medium scale production facility, and would have to operate through large government subsidies. The **weak business case for biodiesel production** is supported by previous studies and it is thus **not recommended to pursue single source commercial scale biodiesel production** within the Western Cape Province.

One of the constraints to commercial scale biodiesel production in the Province is the availability of a single feedstock to meet the biodiesel demand. It is thus proposed that **multiple feedstocks are used to produce biodiesel**. This can be done by developing policies and strategies to motivate and incentivise farmers and other relevant industries to install **multiple on-site small scale biodiesel production facilities**. In doing so, a variety of feedstock types become available for biodiesel production. This includes feedstock like waste vegetable oil and residues from food-crops that were previously inaccessible to the biodiesel production market due to financial implications and logistical issues. This will also result in better utilisation and management of waste and residue streams for the production of biodiesel.

It is proposed that a single entity has the responsibility to facilitate and coordinate the combined effort of multiple small scale production facilities. The single managing entity should provide expertise and advice on biodiesel production in terms of facility and process management. The management should oversee quality control and distribution to ensure that the independent efforts of the small scale producers are well directed and aligned. Controlling quality and distribution of multiple production sources centrally will aid in ensuring that the biodiesel demand of the Western Cape Province is optimally met.

In order to improve the business case, it is recommended to **reassess the biodiesel value stream**. Considering the numerous constraints to biodiesel production, it is likely that improving the financial feasibility will lie in a combination of activities and initiatives. These activities and initiatives should include reducing costs wherever possible and investigating the possibility of incorporating value adding activities into the process. Activities could include finding a market for the glycerine produced as a by-product or even processing glycerine further into a usable product that can generate additional income within the value stream. In this scenario glycerine, will be seen as a co-product to biodiesel production.

It is evident that an innovative approach is necessary if the Western Cape Province is to form part of the blending mandate for biodiesel. In addition, experts from a variety of industries will be required and some of the general recommendations made in the following section will have to be addressed.

5.1.3 General

The first general recommendation affects stakeholders on all levels, but can only be addressed by high level government stakeholders. A **final and comprehensive policy on biofuel pricing structures and qualifying criteria** should be approved and published, as numerous uncertainties exist, which are currently deterring any investment on a local and international level.

Once the pricing structures and service level agreements are clarified as part of the mandatory blending policy, it should be possible to perform an in-depth analysis of the bioethanol and biodiesel value streams. These reassessments should include establishing the exact market value of by-products and comparatively analysing the financial feasibility of implementing value adding activities to increase the overall revenue of the biofuel value stream. Through the addition of value adding activities, various spin-off industries could arise which will strengthen the financial feasibility of biofuel production, contribute to the GDP and create additional employment.

Additional revenues could be generated once certainty has been established regarding the carbon trade and taxing policies in SA. This is supported by the UNTT Working Group on Sustainable Development Financing (2015), who noted the importance of **establishing comprehensive carbon pricing policies** (taxes and emissions trading). These policies are required in order to integrate the aspects of sustainable development projects as part of the mainstream project financing and add to the value stream of sustainably orientated projects. It is expected that the National Treasury will implement carbon emissions tax in mid-2016, which could provide an opportunity for carbon trading to be incorporated as part of the business case for biofuel production (Engineering News, 2015).

From the pretext, it can be deduced that establishing a biofuel production sector in the Western Cape Province will require the amalgamation of efforts from various stakeholders on a variety of different levels, from policy formation and structuring, to local and foreign investors and direct labour and management. The various stakeholders will be the key driver to establishing the biofuel production sector at the hand of the recommendations made.

5.1.4 Stakeholders and adverse effects

Some of the recommendations made relate directly to specific stakeholders mentioned, while other recommendations concern all stakeholders. Although not all stakeholders will be involved in establishing a biofuel production sector, they could be affected by the market. Some of the most prominent stakeholders include: Western Cape Government, National Government, Agricultural Sector in the Western Cape Province and SA, Oil/Fuel Companies (National and International), Investors (National and International), Animal Feed Industry (eg. Animal Feed Manufacturers Association (AFMA) and AFGRI Animal Feeds) and the Western Cape population as consumers.

The diversity of stakeholders and sectors that constitute the biofuel sector is likely to cause numerous adverse effects that were not included in the model, due to the difficulty of quantifying these effects. Initial effects that can be expected include: cost savings due to the reduced logistics of grain carriers, job creation and economic growth through various spin-off industries. Other macro economic effects could result due to the use of biofuel that will displace a portion of fossil fuel/crude oil that would normally be imported, resulting in a notable amount of local currency not leaving the country and that could be used locally to contribute to the economy. Environmental effects like reduced risk of oil spills and ground leakage can also be expected through the displacement of fossil fuels. The complex nature of biofuel does however imply that not all of the adverse effects of biofuel production can be foreseen and stakeholders should pro-actively intervene and mitigate possible negative effects. Negative effects could include the plummeting of the animal feed market prices, due to the large expected influx of DDGS and oilcake as a result of biofuel production.

5.2 Model Limitations and Challenges

The limitations and exclusions of the model have been highlighted in previous sections and are summarised here. The main model limitation was dynamically integrating the model with other sub-models representing various sectors within the Western Cape Province. Although inputs are received from the agricultural and transport models, the biofuel model does not feed back into these models and therefore does not show the adverse effects of biofuel production on the respective sectors. More insights could be gained if the biofuel sub-model could feed and receive feedback into an employment, water, energy and GDP model. Incorporating these feedback effects would likely bring deeper insights through witnessing certain expected but unpredictable emergent behaviour.

Assumptions and uncertainties around pricing, future pricing structures and changes in market values (biofuel sales price, BFP, DDGS and oilcake sales price, energy costs etc.) limit the biofuel model, as the model assumes growth based on historical trends. The model is fit for its purpose and provides the necessary trends regarding key intervention areas, but limitations can be addressed through future work.

5.3 Future Work

Suggested future work entails building on the current system dynamic models in the transition to a green economy in the Western Cape Province. The future models should incorporate established pricing and policy structures and interconnect the sub-models in order to accurately represent feedback between different sectors. Expansion of the models can be done at the hand of the recommendations and limitations discussed in the previous section. Further modelling efforts could be directed to build a biofuel model on a national level that would indicate the feasibility and effects of the combined biofuel production potential of SA. Using a system dynamic model of biofuel in conjunction with supply chain modelling techniques on a national level could possibly indicate various opportunities and ways to overcome the current constraints, i.e. through effective resource sharing and value chain management.

5.4 Study Limitations and Recommendations

Leading up to the conclusion of the study, certain limitations and challenges emerged as part of the study, and are discussed here. While a sound research approach was followed to ultimately identify and use system dynamics in order to simulate the effects of biofuel production in the Western Cape Province, most of the challenges that emerged were from the use of system dynamics.

Firstly, the usefulness and applicability of system dynamics is discussed. As mentioned in the literature review, system dynamics is an extremely powerful tool and can holistically describe complex systems. The disadvantage of system dynamics is that it requires extensive knowledge on every part of the system, as it breaks all systems down to the individual root causes and drivers, also calling for a large amount of input parameters and accurate data. Although various industry experts were consulted to assist in identification of the main drivers, some of the drivers may have been overlooked or considered irrelevant (depending on the disposition of the stakeholder). It is thus difficult to build a model that coherently incorporates all of the drivers deemed important by all of the stakeholders, as every stakeholder has a different view and perspective in terms of system boundaries and expectations of what biofuel production entails. Through consultation with industry experts, an attempt was made to mitigate the criticism against system dynamics being a black box approach. This did provide some transparency to stakeholders, but still required the stakeholder to have at least introductory knowledge on the working of system dynamics.

Further difficulty lies in gathering accurate data to populate the model. Biofuel is a relatively new concept in SA, with no medium-large scale operational plants. This resulted in data (scaled to size) being sourced mainly from research efforts on small scale pilot projects in SA and medium-large scale facilities from projects in other countries, which will see some discrepancies in values from an actual medium-large scale operational facility in SA, particularly the Western Cape Province. The unique geographic and climatic properties of the Western Cape Province made it especially difficult to find data, as the feedstock options for biofuel production differ from the rest of the country and triticale is not a common commercially grown crop anywhere else in the country. The lack of data and a business as usual scenario for biofuel makes it difficult to validate the model through the use of historic data and trends.

Based on the available data and the fact that no business as usual case exists for biofuel production in the Western Cape Province, it was first necessary to build a project evaluation model. Unfortunately a project evaluation model requires the use of switches, which results in limited dynamic feedback, as discrete events are not well simulated with system dynamics due to the nature of it. The need for a project evaluation model limited the amount of sectors and feedback that was incorporated in the biofuel model. This leads to the conclusion that the current simulation results would also be obtainable through extensive mathematical calculations in a spreadsheet (e.g. Microsoft Excel). The value lies in the developed model providing the groundwork for biofuel studies and policy testing in the Western Cape Province, as the developed model can be incorporated into larger models and expanded once there is more clarity on the policies and project structures. The model in its own right could thus be seen as an over-complicated project evaluation, but once incorporated into a larger structure where it is giving and receiving feedback to and from a variety of markets and sectors, the model can dynamically simulate the various outcomes of biofuel production within the Western Cape Province.

It is thus recommended that the biofuel model be further developed as part of a larger system, where experts and stakeholders from concerned sectors, attend a facilitated workshop. To make stakeholder engagement as easy as possible, system dynamics experts can facilitate and guide a critical discussion about the main drivers and effects of each sector to gain valuable and accurate information from stakeholders. Each sector model is then refined, and subsequently incorporated into an encompassing model that can accurately indicate the high level effects of biofuel as part of a green economy transition in the Western Cape Province.

5.5 Concluding Remarks

In conclusion, this study addressed and reached the research objectives through selecting and using system dynamics to identify, and provide recommendations on, the key strategic intervention areas for establishing a biofuel market in the Western Cape Province. The feasibility of building and operating a medium-large scale bioethanol plant (without requiring a subsidy) was established. Recommendations were made regarding the key areas to address in order to improve the business case for bioethanol, biodiesel and biofuel in general. The study supported previous findings that the business case for medium-large scale biodiesel plant in the Western Cape Province is not strong and should not be pursued. The system dynamic model showed the influence of different biofuel production scenarios and how the different drivers ultimately affect factors like emissions, feedstock requirements and operational cost.

The study could be used as a foundation for analysing the effects of different policies and structures regarding biofuel production within the Western Cape Province. It is expected that biofuels will form part of the Province's green economy transition and this model could help to shape and inform strategic decision making.

The model was developed to show how biofuels fit into the establishment of a green economy transition in the Western Cape Province. The model only indicates the immediate effects of biofuel production (as part of the green economy) and it is recommended that future problems of this nature should be modelled by consulting with industry experts first. Through consulting with industry experts, valuable insights can be gained on how a particular system interacts with other systems, and where the common/interfacing areas between systems are, to ensure that all of the sub-models are designed and built in a way that can incorporate feedback from one another as part of a larger system.

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Appendices

Appendix A

Introduction to Biofuels

The concept of biofuel involves converting living or previously living material to energy. Exploring the capabilities of different biomatter to produce energy has been a key focus area of many researchers since the inception of biofuel. This search has lead to the development of two main combustion fuel products, namely bioethanol and biodiesel, which have the potential to replace mineral based fossil fuels (Solomon, 2010; Sexton *et al.*, 2006). The use of biomass as a replacement for fossil fuels is based on the following three reasons, as given by Balat and Balat (2009):

1. Renewable resource which can be sustainably developed;
2. Positive environmental effect with no nett carbon releases and low sulphur content; and
3. Notable economic potential (assuming that rise in fossil fuel prices continue on current trajectory).

A.1 Bioethanol

The use of bioethanol is especially viable as it can be used in both pure and mixed form, while requiring minimum modifications to infrastructure and internal combustion engines. Bioethanol is considered an oxygenate fuel and has further properties causing it to burn cleaner with increased efficiencies, when compared to petroleum based fuel. These properties include a higher octane content, higher vaporization heats and flame speed and broader flammability limits, making it ideal for use in internal combustion engines. Bioethanol is however not without its disadvantages and has a lower energy density, higher corrosiveness, difficulty with cold starts (due to lower vapor pressure) and an increase in emissions of acetaldehyde (which has been known to contribute to air and water pollution) (Balat and Balat, 2009).

Bioethanol is divided into two generations, where first generation bioethanol can be produced from a variety of crops, which falls into three main groups as indicated in Table A.1 (Agarwal, 2007; Balat and Balat, 2009). The second generation feedstock aims to have improved efficiency in terms of the water and land usage and other environmental effects (Sexton *et al.*, 2006).

Table A.1: Bioethanol feedstock

Bio-ethanol groups	Feedstock
Sucrose containing	sugar cane sugar beet sweet sorghum fruits
Starchy Materials	corn wheat rice potatoes cassava barley
Lignocelluosic biomass	wood straw grasses

Various studies have identified sorghum, sugarcane and sugar beet as the main feedstock for commercial bioethanol production in SA (The Department of Energy, 2014). The Western Cape Province as a winter rainfall region, has a unique climate and a distinguished agricultural sector. The ideal crops for bioethanol production in the Western Cape Province are from the starchy materials section, which specifically include wheat, rye, barley and triticale.

A.2 Biodiesel

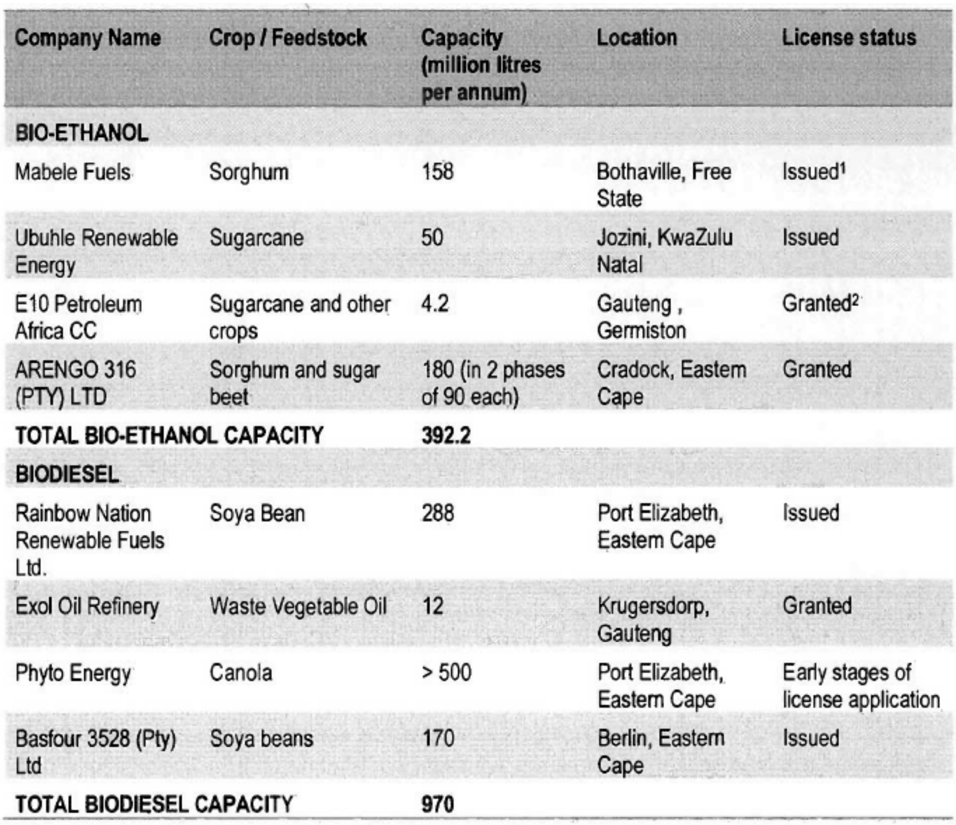
Biodiesel is an attractive alternative to fossil fuels and has long been used to fuel diesel engines. It can be blended with petroleum diesel or used in pure form (B100), but the use of pure biodiesel is less common due to the solvent-effect which has been known to cause clogging of some engine parts. The use of biodiesel provides many advantages which include but are not limited to: providing a prolonged engine life due to lubrication effect, improved combustion process (oxygenate fuel), biodegradable, does not contain sulphur, reduced CO_2 emissions and it is non-toxic.

Biodiesel is mainly produced through two types of raw materials; oil or oil based foodcrops. The process of producing biodiesel is called transesterification and is a reaction of oils/fats with an alcohol in the presence of an alkaline catalyst. The oil used in production can be pure vegetable or waste vegetable oil. Oil based foodcrops are also grown specifically for the production of biodiesel, where the most commonly used foodcrops include; rapeseed, sunflower, soybean and palm oil. The alcohol (usually methanol) is added to produce methyl esters, also called Fatty Acid Methyl Esters (FAME), and the catalyst is normally Sodium or Potassium Hydroxide. The production process also delivers glycerine as a by-product, which does have some market value and can be used in the production of lotions, cosmetics and soap (Sales, 2011).

It is expected that biodiesel will contribute significantly to the diversification of the fuel supply mix because of its renewable nature and relatively simple production process involved. However, the production of biodiesel in SA and specifically the Western Cape Province is curtailed by some disadvantages, which include a high cost of production compared to fossil fuel based diesel, as well as the high cost and unavailability of feasible feedstocks.

Appendix B

National Biofuel Strategy - Information



Company Name	Crop / Feedstock	Capacity (million litres per annum)	Location	License status
BIO-ETHANOL				
Mabele Fuels	Sorghum	158	Bothaville, Free State	Issued[1]
Ubuhle Renewable Energy	Sugarcane	50	Jozini, KwaZulu Natal	Issued
E10 Petroleum Africa CC	Sugarcane and other crops	4.2	Gauteng , Germiston	Granted[2]
ARENGO 316 (PTY) LTD	Sorghum and sugar beet	180 (in 2 phases of 90 each)	Cradock, Eastern Cape	Granted
TOTAL BIO-ETHANOL CAPACITY		**392.2**		
BIODIESEL				
Rainbow Nation Renewable Fuels Ltd.	Soya Bean	288	Port Elizabeth, Eastern Cape	Issued
Exol Oil Refinery	Waste Vegetable Oil	12	Krugersdorp, Gauteng	Granted
Phyto Energy	Canola	> 500	Port Elizabeth, Eastern Cape	Early stages of license application
Basfour 3528 (Pty) Ltd	Soya beans	170	Berlin, Eastern Cape	Issued
TOTAL BIODIESEL CAPACITY		**970**		

Figure B.1: Status of Applications for Biofuel Manufacturing Licenses (Department of Minerals and Energy, 2007)

Appendix C

Model Structures

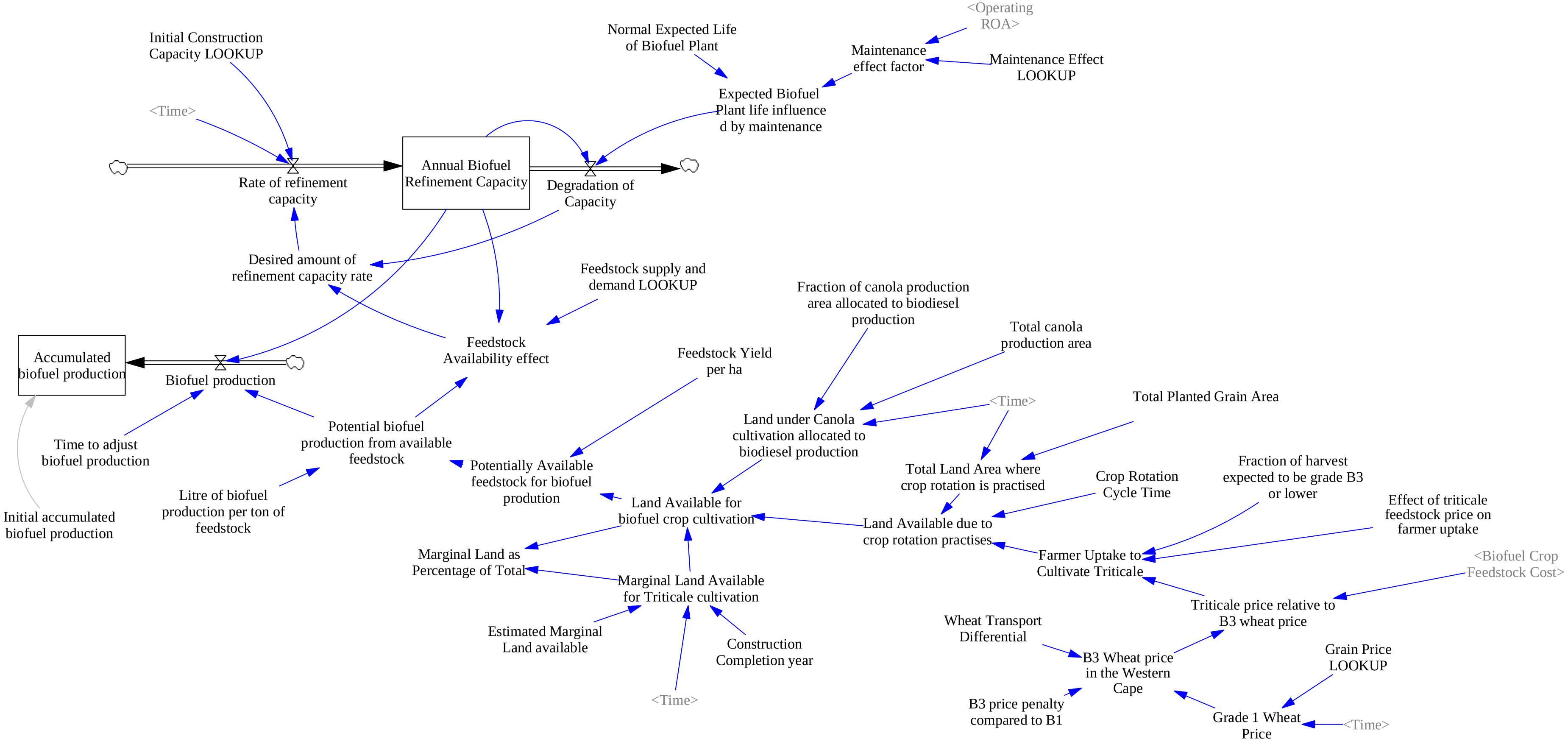


Figure C.1: Biofuel production

C.1 Agricultural Yield

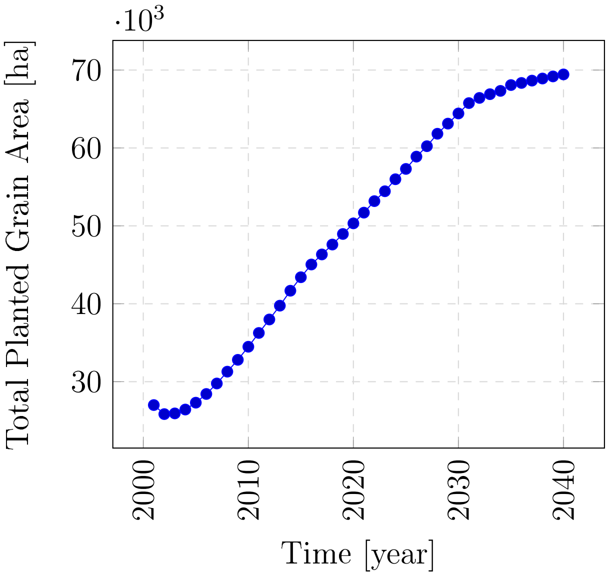


Figure C.2: Total planted canola area

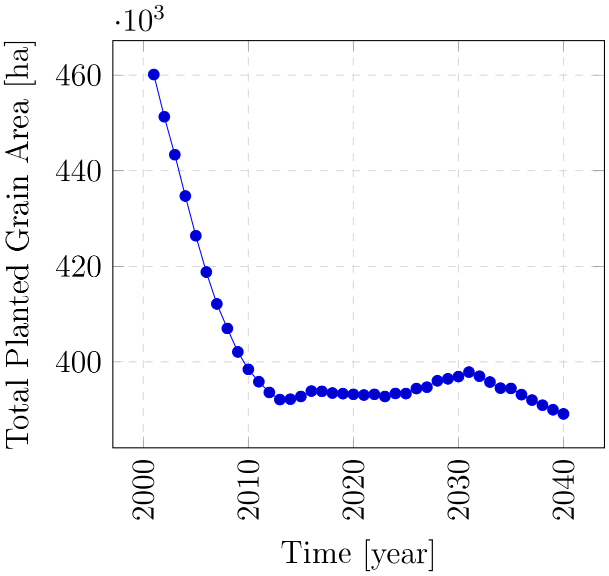


Figure C.3: Total planted grain area

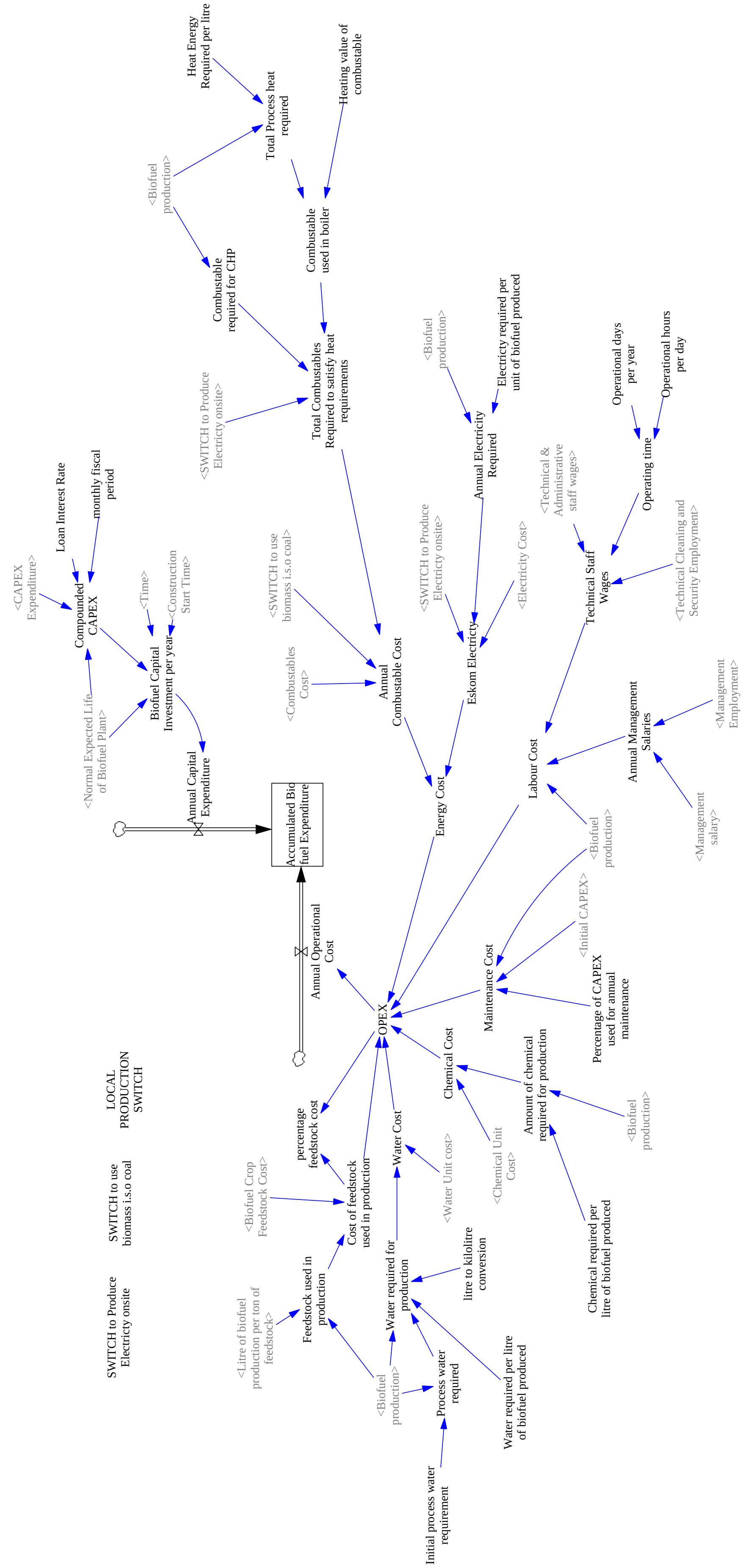


Figure C.4: Biofuel expenditure

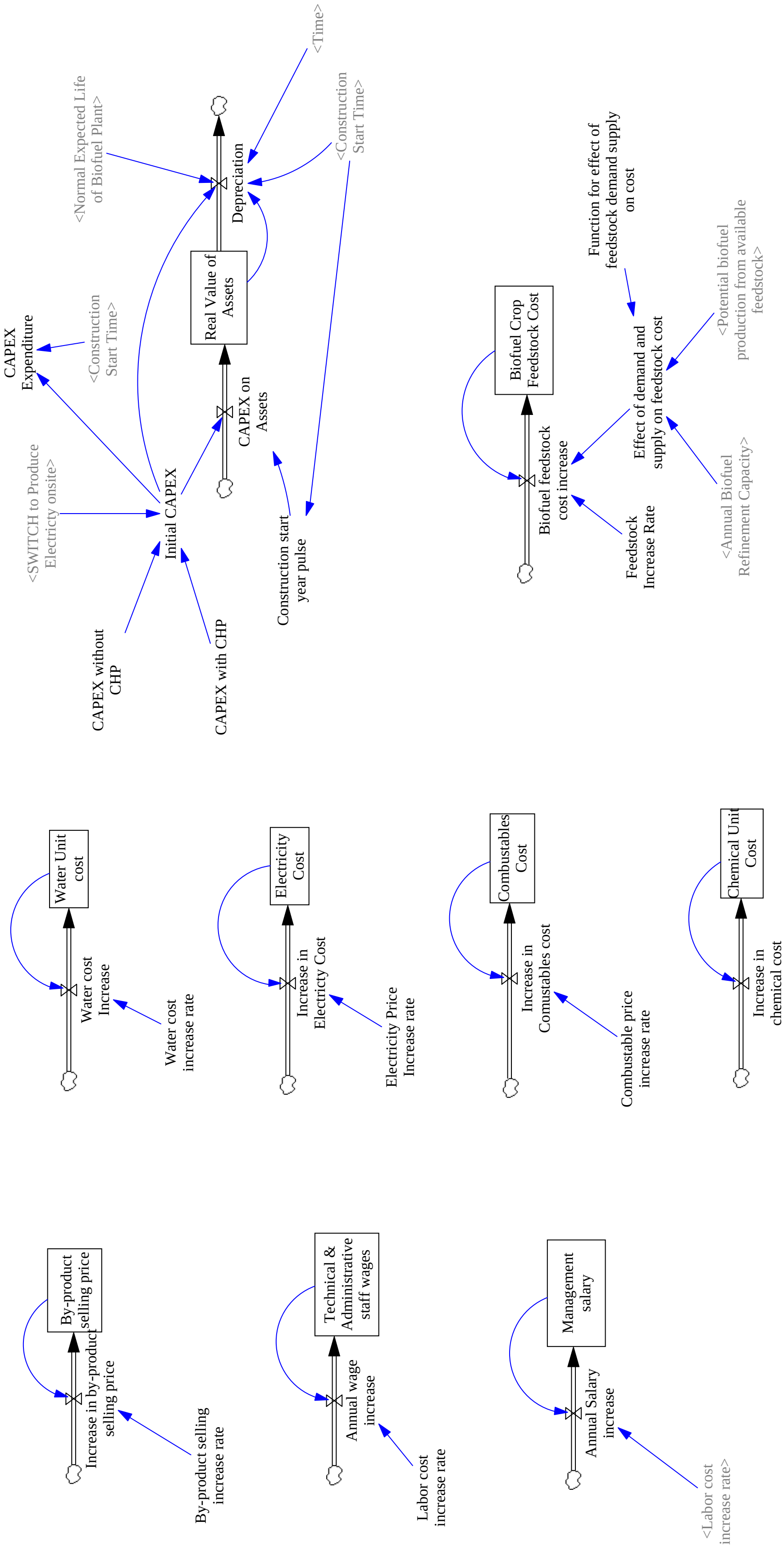


Figure C.5: Operational finances

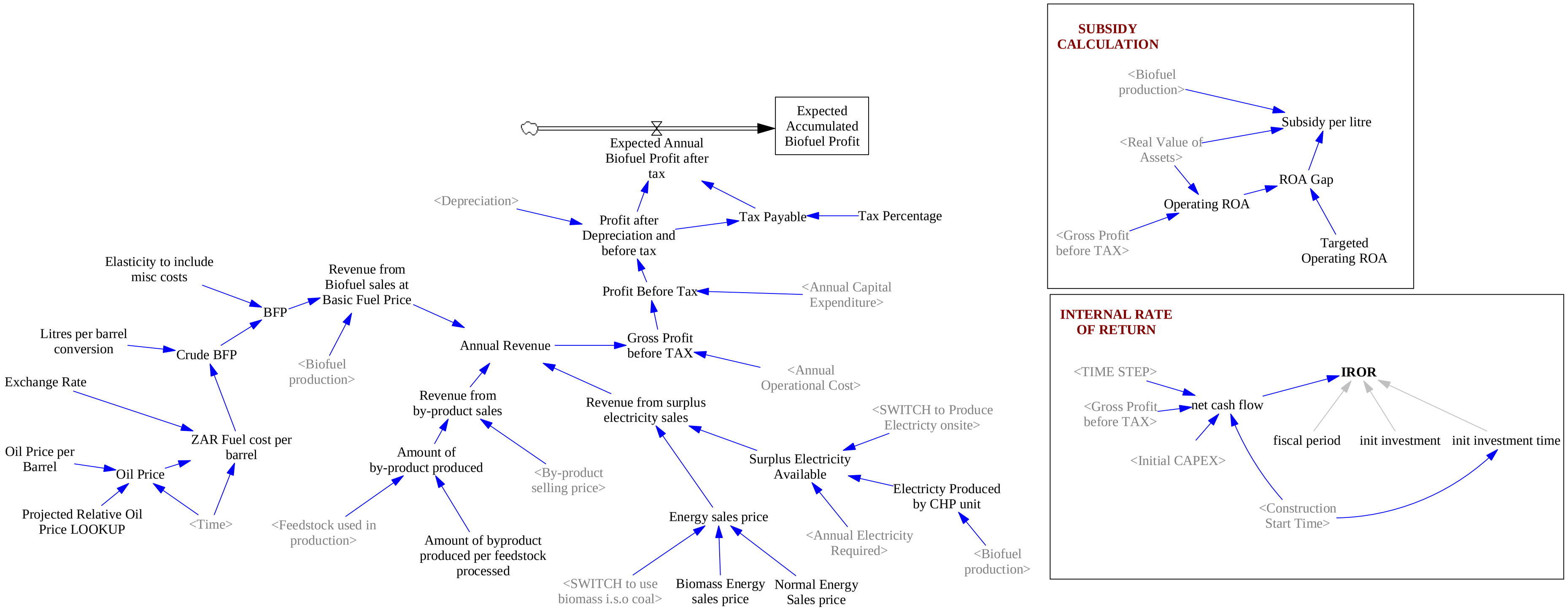


Figure C.6: Profitability

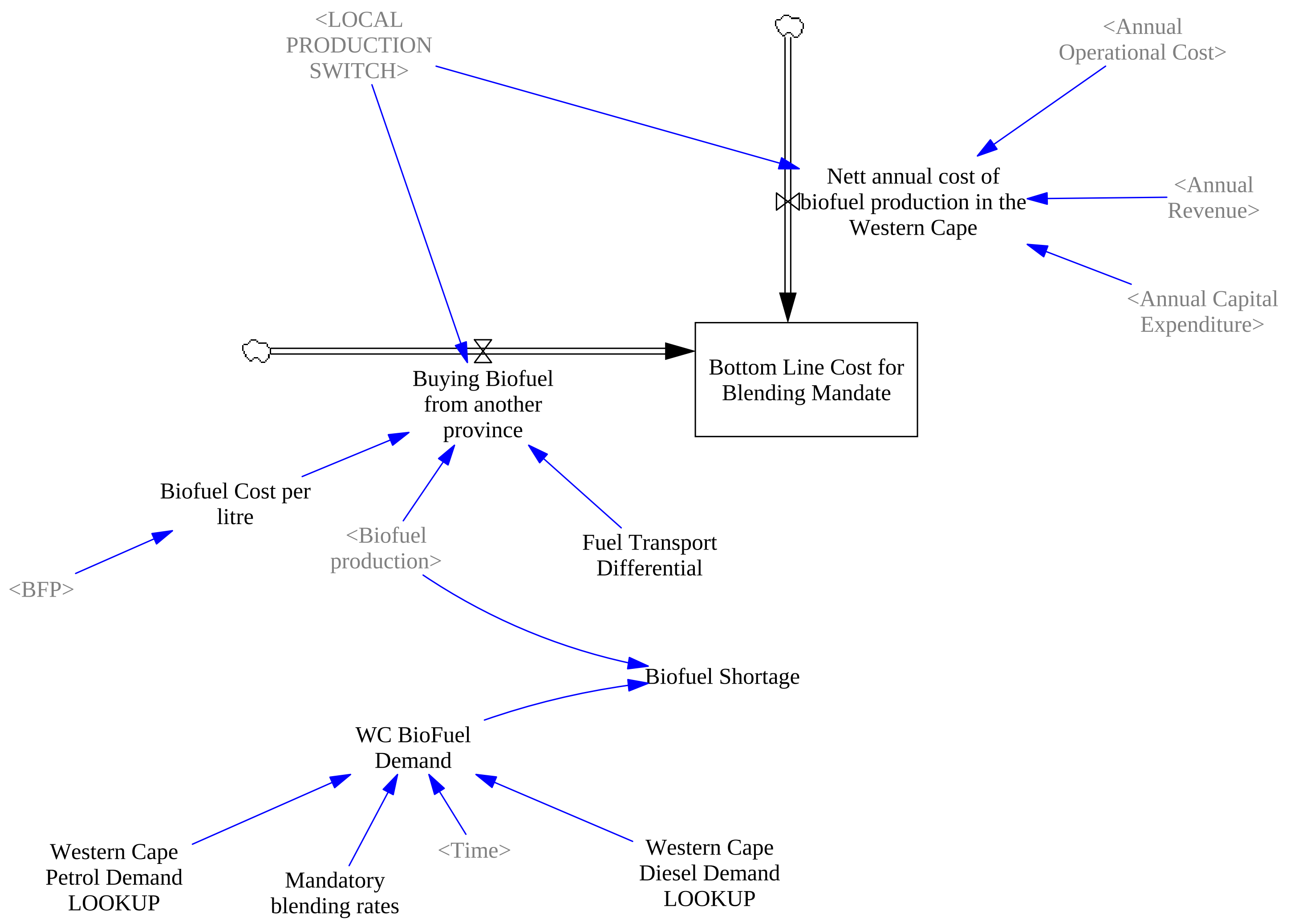


Figure C.7: Bottom Line Cost

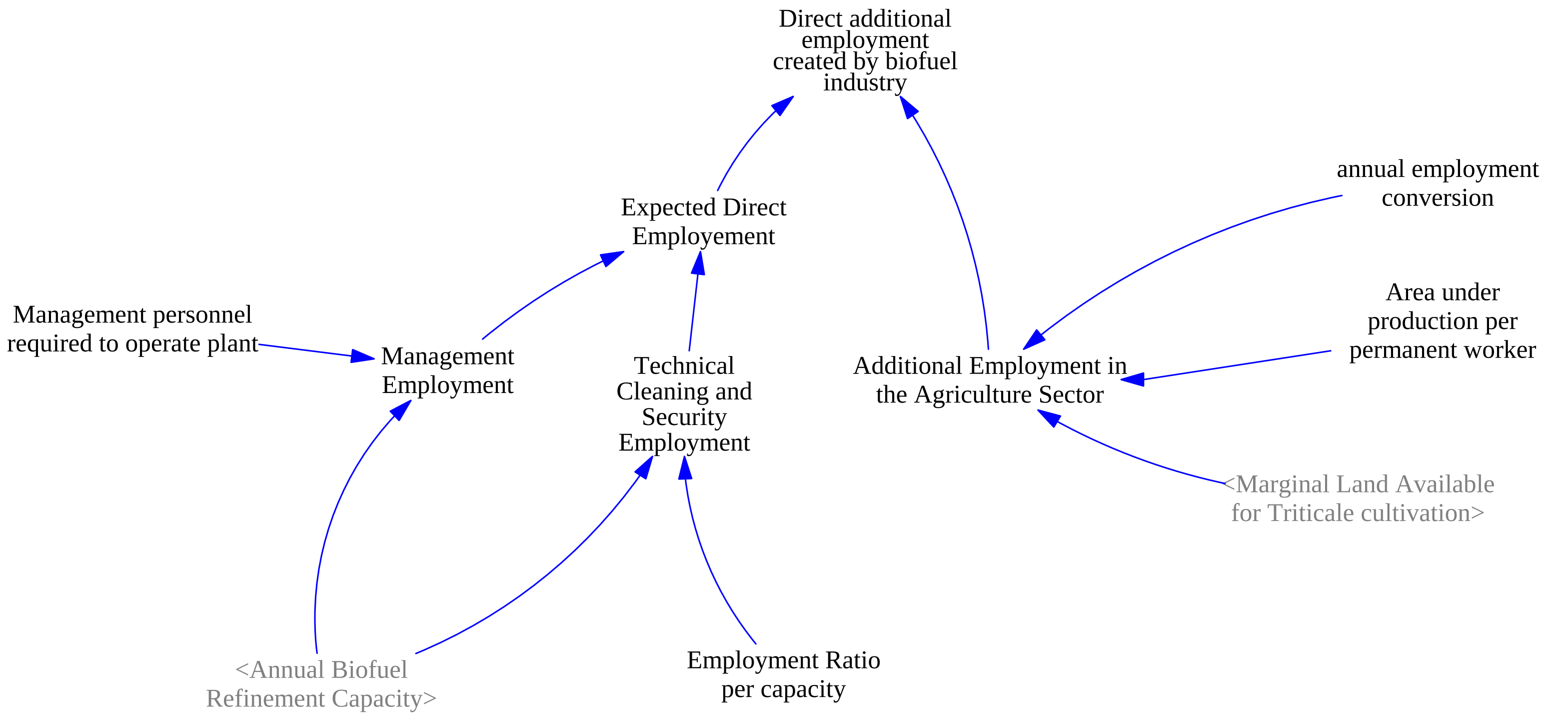


Figure C.8: Employment

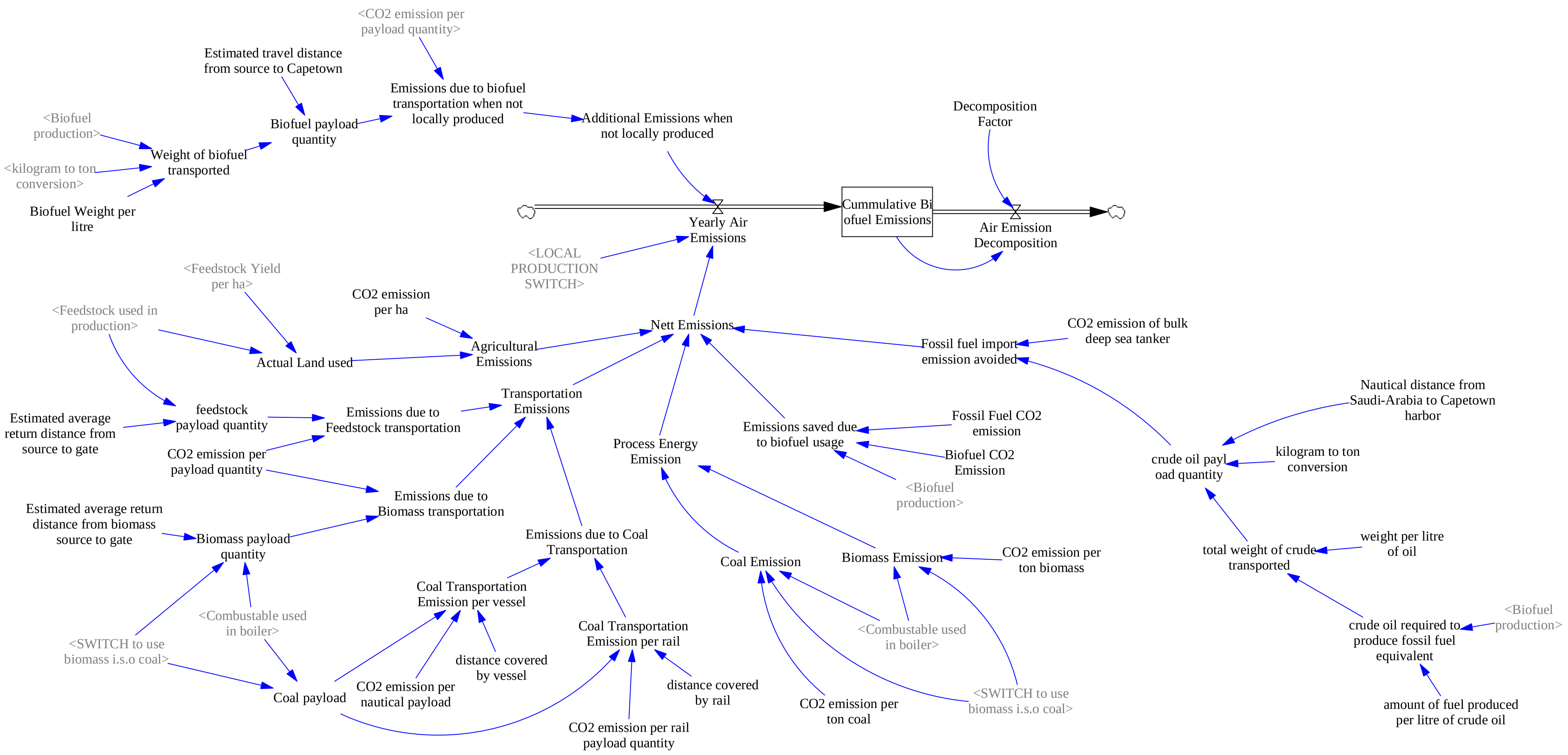
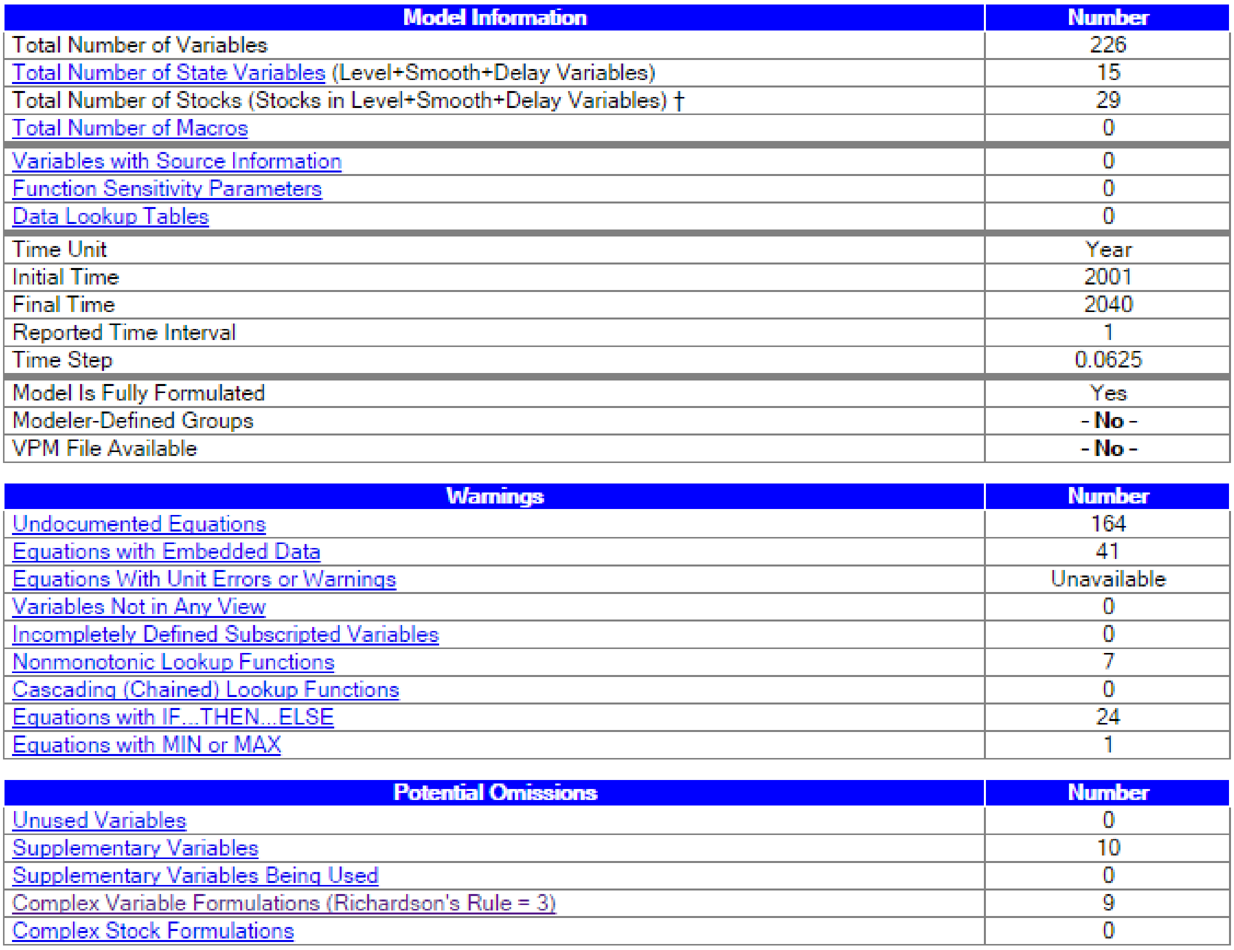


Figure C.9: Emissions

Appendix D

SDM Validation



Model Information	Number
Total Number of Variables	226
Total Number of State Variables (Level+Smooth+Delay Variables)	15
Total Number of Stocks (Stocks in Level+Smooth+Delay Variables) †	29
Total Number of Macros	0
Variables with Source Information	0
Function Sensitivity Parameters	0
Data Lookup Tables	0
Time Unit	Year
Initial Time	2001
Final Time	2040
Reported Time Interval	1
Time Step	0.0625
Model Is Fully Formulated	Yes
Modeler-Defined Groups	- **No** -
VPM File Available	- **No** -

Warnings	Number
Undocumented Equations	164
Equations with Embedded Data	41
Equations With Unit Errors or Warnings	Unavailable
Variables Not in Any View	0
Incompletely Defined Subscripted Variables	0
Nonmonotonic Lookup Functions	7
Cascading (Chained) Lookup Functions	0
Equations with IF...THEN...ELSE	24
Equations with MIN or MAX	1

Potential Omissions	Number
Unused Variables	0
Supplementary Variables	10
Supplementary Variables Being Used	0
Complex Variable Formulations (Richardson's Rule = 3)	9
Complex Stock Formulations	0

Figure D.1: SDM Validation