MODELLING THE PRODUCTION OF BIOFUEL WITHIN THE WESTERN CAPE PROVINCE, SOUTH AFRICA

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ABSTRACT

The Western Cape Government of South Africa has identified the biofuel industry as a key role player in the government's effort to transition towards a green economy and becoming one of the leading green economic hubs of the African continent. The focus of this paper is on investigating the potential and effects of commercially producing biofuel. Various modelling techniques are reviewed in order to determine which technique would be most suited for modelling the potential impacts of policies and drivers regarding biofuel production in the Western Cape Province.

In order to determine the most appropriate modelling technique, a literature survey was completed. This included a systematic review of available literature whereby the context and origin of biofuel production was investigated. The complex and intricate causal nature of biofuel required a brief look into systems thinking and complex systems theory. The literature on transition theory was also systematically reviewed in order to investigate and describe the effect of biofuel production on the transition towards a green economy. A conceptual review process was used to give an overview of some of the aspects involved in the modelling of complex interactions. The multidimensional approaches to facilitate the transition towards sustainability is discussed within the modelling context and it is concluded that System Dynamics modelling will be the most appropriate technique for modelling biofuel production.

An aggregated model is used to indicate the qualitative relationships and causal nature of the stakeholders and drivers in biofuel production. The model considers triticale and canola oil to produce bioethanol and biodiesel respectively. The feedstock was identified to be the most lucrative and feasible in the Western Cape. Identifying the various interactions present in the system, a system dynamic model will be built to indicate the overall potential of the Western Cape to produce biofuel (specifically looking at the business case for using triticale and canola oil, as well as the land use implications and employment creation possibilities). In conclusion it will be possible to critically assess the potential to produce biofuel and make recommendations regarding the appropriateness of current policies and initiatives.

Key words: South Africa, Western Cape, biofuel, bioethanol, biodiesel, modelling, system dynamics

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INTRODUCTION

The fast moving industrialisation and urbanisation of the world has led to a dramatic increase in the economic welfare of a large group of people which vastly expanded the middle class population (Katyal 2009). With more people now tapping into the global resource pool, the natural resources are placed under extreme pressure. This necessitated the need for 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, through alleviating poverty. It further recognises the interdependence of development, the environment and human actions and needs. Sustainable development has its early roots in 1980 and became more defined in 1987 when the World Commission on Environment and Development (WCED) issued the report "Our Common Future". The report stipulated the close interaction between social, environmental and economic issues as part of global growth and development. The UN conference on Environment and Development (UNCED), held in 1992, developed Agenda 21, "A Programme of Action for Sustainable Development". This can be seen as the initiation of implementing policies and strategies to control development by integrating the three pillars of sustainability namely; social, environmental and economic. (Sustainable Development Knowledge Platform 2011)

Many implementation techniques and tools have been developed in order to drive sustainable development. One of the more recent and relevant concepts is the transition to a green economy. The green economy was defined by the United Nation Environment Programme (UNEP), as "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). The green economy has been identified to play a critical role in the implementation of sustainable development. A transition to a green economy will involve parties from the public and private sectors and requires participation on all levels in eradicating poverty in a way that is resource efficient and economically viable.

The green economy principle is especially applicable to third world countries, which rely mainly on natural resources to drive the economy and sustain the populations' livelihood. With South Africa (SA) owing a sizeable portion of its gross domestic product (GDP) to the use and export of natural resources, the country is greatly dependent on the efficiency of its resource utilisation. In the light of this knowledge the South African government released the National Development Plan (NDP), describing guidelines to transform the South African economy to an environmentally sustainable low carbon economy (National planning Commission 2012). The NDP further states that there should be a transition from policy to process to action. While policies are developed on a national level, each of SA’s nine provinces faces unique problems. Provincial bodies are thus required to adapt and implement policies in a way best suited for their specific environmental, demographic and social needs. The Western Cape government (WCG) created a framework in order to become the lowest carbon province and a leading green economic hub of the African continent. The framework identifies the drivers for a green economy. Transportation was highlighted as one of the big contributors in producing greenhouse gasses (GHG) (Green Cape 2013, Western Cape Government 2013).

The use of biofuels has long been a popular choice to reduce carbon emissions and to shift away from ever decreasing and uncertain petroleum based fuel supplies (Solomon 2010). In order to reduce carbon emissions and contribute to a green economy transition, the SA national government has implemented a policy, which requires the mandatory blending of the fuel pool with at least 2% of biofuel by October 2015. In order to meet this demand for an estimated 400 million litres of biofuel per year, a number of biofuel production facilities have been approved for construction. This includes the construction of four bioethanol and four biodiesel plants in the Free State, KwaZulu Natal, Gauteng and Eastern Cape provinces. Based on the fact that the Western Cape is not explicitly included as part of the national biofuel production plan, the WCG completed a number of independent studies to determine the capability of the Western Cape to produce biofuel and contribute toward the transition to a green economy (The Department of Energy 2014).

The concept of biofuel involves converting living or previously living material to fuel. Exploring the capabilities of different biomatter to be converted to useable energy has been a key focus area of many researchers since the inception of biofuel. This search has led 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 reasons, as given by Balat & Balat (2009):

i. Renewable resource that can be sustainably developed.
ii. Positive environmental effect with no net carbon releases and low sulphur content.
iii. Notable economic potential (assuming that rise in fossil fuel prices continue on current trajectory).

More detailed information on biofuel can be found in the Appendix.

The need for diversifying the energy supply mix of SA was first established in 1998 when the then Department of Minerals and Energy (DME) published a white paper on energy policy. The paper acknowledged the need for increased efficiency and diversification of the liquid petroleum fuel supply for the transport sector in order to reduce the GHG emissions while contributing to the economic and social growth within SA (Department of Minerals and Energy 1998). The events that lead to the implementation of the policy on mandatory biofuel blending by October 2015 are summarised in the Biofuel Industrial Strategy (2007) (Department of Minerals and Energy 2007).

Growth within the biofuel industry has been driven by numerous factors which include support for renewable energy, support of more environmentally friendly energy sources and boosting the local agricultural sector, while attempting to limit global warming. There is a vast network of resources, policies, regulations and drivers involved in the biofuel industry. Some of the major concerns regarding the commercial production of biofuels include water limitations, food security, land value, land availability, biofuel quality, crop selection, fuel levies, subsidies and the effect on the agricultural sector (Amigun et al. 2008, Musango 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 the amount of complex interactions and actors involved that can’t be understood in a linear fashion. This requires modelling techniques to be used along with systems thinking in order to assist in policy development where various scenarios can be modelled to evaluate the qualitative and quantitative effects on the resources involved. By studying the quantitative predictions within the context of a transition to a green economy it may be possible to eventually develop a near optimal approach to biofuel production on a commercial scale within the Western Cape Province of South Africa.

Systems Thinking, and Complicated and Complex Systems

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. Maani and Cavana (2007) define systems thinking 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: (1) Thinking of the "big picture"; (2) Balancing short-term and long-term perspectives; (3) Recognising dynamic, complex and interdependent nature of systems; (4) Taking measurable and non-measurable factors into account; (5) Noting the presence of feedback loops; (6) Distinguishing between cause and symptom and (7) 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 are indicated in Figure 1. (Maani, K. & Cavana, R. Y. 2007)

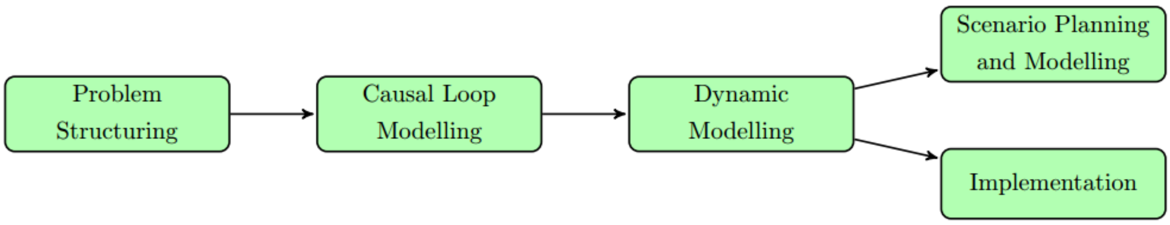

Figure 1: Modelling Phases

Complex systems theory has to be used in order to represent reality closely, as Norman (2011) explicitly defined:

"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"

From this definition it seems that a complex system is often chaotic and radical due to the dynamics and feedback involved. The one factor distinguishing a chaotic and complex system however 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. This makes complexity theory well suited for modelling of real life situations like biofuel production (Norman 2011).

In order to model a complex system it is important to note the following characteristics, defining a complex system (Radford 2008):

i. Numerous variables interacting simultaneously.
ii. Non-linear and dynamic causal interactions.
iii. Vague boundaries.

iv. Unforeseeable new variables arising.

When viewing these characteristics it is possible to draw a correlation between a complex system and the concept of sustainability. This is illustrated by identifying sustainability as being part of a Social-Ecological System (SES), Dawson *et al.* describes a SES to be a form of Complex Adaptive System (CAS). 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 the actions of other actors (Dawson et al. 2010).

Dealing with Complexity

In order to accurately analyse the potential of the Western Cape to produce biofuel, it is important that the correct approach be used to predict the effects and possible outcomes of the complex system. A variety of methods are available to researchers. The pitfalls and advantages of some of the most relevant methods are investigated in order to select the most applicable method for the evaluation of biofuel production.

As a complex system a number of factors have to be considered when reviewing and assessing the methodologies and models that can be used to analyse the transition of the WC to a green economy. In order to generate and analyse simulations of social, economic and environmental scenarios, data frameworks and modelling methodologies have to be considered. Data frameworks generally deal with static information while modelling is based on dynamic factors; however data frameworks often form the core of modelling approaches. This is based on the consideration that data frameworks 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 for the indicators of the system. It is thus important to use dynamic methodologies when it is required to create a quantitative simulation model that would be able to engender future predictions. These dynamic modelling methodologies include econometrics, optimisation and system dynamics (SD) (Bassi 2014).

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. The focus is thus placed on exploring and selecting the most applicable dynamic methodology or modelling technique.

Econometrics

Econometrics is the application of statistical methods to quantify and asses the hypothetical relationships between role players using the data available (Dougherty 2011). Econometrics is a powerful modelling approach used to find correlations between variables. 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). It is impossible to capture the full rationality of some elements in the model and the availability of accurate data has always been a major limitation in econometrics (Bassi 2014).

Although numerous techniques have been developed whereby econometrics can be used to predict future outcomes, many of these techniques rationalise data and variables resulting in the approaches neglecting the dynamic linkages amongst the variables and making feedback effects difficult to model.

The main factors that exclude econometrics from being a feasible model to explore the potential of a transition to green economy is however, 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). 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.

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, second is the area of intervention and the last is the constraints that apply to the system (Bassi 2014). 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.

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. 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 into various goal functions and then further establishing 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.

Many optimisation techniques exist (Integer Programming, Search Heuristics etc.) which improves the amount of detail that can be provided and overcomes the shortcomings of LP, but this has proved to be a time consuming and costly way to obtain accurate optimisation results (Turner et al. 2002). 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.

System Dynamics

System Dynamics uses a top-down approach and directly incorporates systems thinking to describe, model, simulate and analyse CAS. System Dynamics combine the principles and techniques involved in control and feedback systems with structure of social, environmental and economic problems (Pruyt 2013). The strengths 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 framework on an aggregate level.

A System Dynamics approach sets out to understand what the main drivers for the behaviour of a system is (Bassi 2014). SD has been used extensively in policy testing and forecasting and it is favoured for its ability to indicate consequences and outcomes of disruptions and deviations from the normal pattern or historical state. This does however imply some shortcomings of SD, which include that causal loop diagrams are based on the modeller's knowledge in identifying possible changes or disruptions. Some of the functions and parameters within 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 SD 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. This makes SD an attractive option for modelling the transition to green economy and the potential of biofuel, as it can accurately describe a variety of outcomes for different policy changes and disruptions in other complex interactions.

Discrete Event Simulation

Discrete Event Simulation (DES) 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. 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 et al. 2004).

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). 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 processes and flows involved in any system (Sumari et al. 2013).

Agent Based Modelling

Agent Based Modelling (ABM) in contrast to SD uses a bottom-up approach based on agent level interaction. 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 et al. 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).
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. For ABM to accurately model the outcomes of a system, it is however necessary to have an idea of the processes that the individual participants follow in their behaviour.

ABM is intended to go well beyond the abilities of SD but is much harder to develop useful models because it requires extensive knowledge on the behaviour of individual factors. It should therefore only be used when the system cannot be accurately modelled by using SD or Discrete Event Simulation (Borshchev et al. 2004).

Transition to Sustainability

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). 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. 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). 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 shown in Table 1 and include Transition Management (TM), Strategic Niche Management (SNM), Multi-Level Perspective (MLP) and Technological Innovations Systems (TIS).

Table 1: Approach to transitions

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	- Takes a holistic approach. - Middle-range theory that describes the overall social-technical transition, in terms of three analytical levels: niches, regimes and the exogenous landscapes (Geels 2011).
Technological Innovations Systems	- Looks at emerging socio-technical configurations. - Uses the potential of emerging actors to contribute in the transitions towards a predetermined goal (Coenen et al. 2012).

It is likely that all four of the above mentioned 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; these include (Hon et al. 2014):

i. Reluctance to lose control.
ii. Unwillingness to think differently.
iii. Lack of psychological resilience (inability to deal with change).
iv. Intolerance to the learning curve/time involved.
v. Preference for low-level stimulation.
vi. Reluctant to give up old habits.
vii. Costs involved.

Objectives

Based on the literature that has been discussed and the context of biofuels within the Western Cape Province, the aim of this research is to identify all of the drivers and actors that will influence biofuel production in the Western Cape, specifically making use of triticale and canola oil for bioethanol and biodiesel respectively. By building a causal loop diagram to indicate the causal nature between all of the role playing factors, it will be possible to develop and build a system dynamic model in order to investigate and simulate the likely outcomes and effects of commercially producing biofuel. The simulations can be adapted to evaluate different scenarios to determine and develop a near optimum approach to policy forming and investment strategies, at the hand of investigating the resulting effects, such as GHG reductions, biofuel shortages, import requirements, infrastructure requirements, agricultural implications and water and land usage issues.

As part of further studies to drive the inclusion of the Western Cape in the Biofuel Industrial Strategy, this paper aims to explore the methods and research currently available to establish and model the potential of the Western Cape to support biofuel production on a commercial scale. The objectives of the study can thus be summarised as follows:

i. Investigate current knowledge and possible interactions of biofuel production.
ii. Place biofuel within the context of the Western Cape and build a causal loop diagram (CLD) to graphically illustrate the complex and dynamic interactions of biofuel production.
iii. Build a system dynamic (SD) model (using Vensim® software) to accurately establish the feasibility and the adverse effects of commercial biofuel production within the Western Cape.

METHODOLOGY

In order to deal with the complexities involved in biofuel production, system dynamics was identified to be the most appropriate technique to accurately model and establish the outcomes and effects of investment into biofuels as part of the transition to a green economy.

System Dynamics

To model the production of biofuel it will first be necessary to identify and define the model boundary and construct a causal loop diagram, which will assist in identifying the correct drivers and actors within the system. A model will be constructed to incorporate the various actors within the Western Cape through links to the stock and flows according to system dynamic structure as shown in Figure 2.

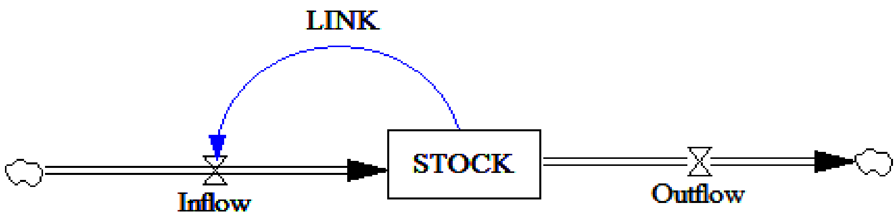

Figure 2: System Dynamics Structure

Causal Loop Diagrams

Causal Loops are used to indicate the dynamic processes present within a system. Causal loops show the chain effects of variables that are related through various links. The causal effect of a variable can thus be traced through an entire causal loop to investigate the adverse effects and eventual influences of all the variables that are linked together to form a causal loop. There are two types of causal loops; Balancing (Negative) and Reinforcing (Positive) (Maani, K. & Cavana, R. Y. 2007).

An example of a balancing (B) causal loop is shown on the left in Figure 3, where it can be seen that an increase in biofuel shortage will lead to an increase in biofuel production, while increased biofuel production will lead to an opposing (decreasing) effect on biofuel shortage. The reinforcing (R) causal loop in contrast, does not decrease and is reinforced by the feedback present in the system. The diagram on the right in Figure 3 shows how increased investment into biofuels will lead to increased revenue due to production, which in turn reinforces investment into biofuels again.

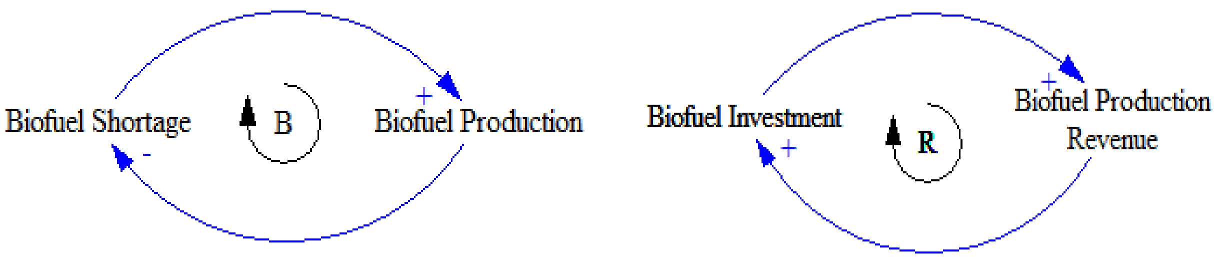

Figure 3: Balancing - (Left) and Reinforcing Causal Loop (Right)

Model Parameters & Validation

The timespan for the model is taken to be from 2001-2040, as the 2001 census provided accurate data with which the various sub-models and stock can be validated. The model does not look further than 2040, as the blending policies come into effect in 2015 and it was concluded that 25 years would be the maximum time in which the Western Cape should respond to such policies.

Model inputs and parameters are obtained from similarly verified and validated models that have been built. Information regarding the Western Cape and the use of triticale and canola oil will be obtained from the involved organisations and industry specialists in the agricultural, biofuel and government sectors.

Validation of the model would be complicated as there are currently no commercial scale biofuel plants operating within the Western Cape. It would be possible to validate the population and fuel demand amongst other sub-models, where historical data is available to use as reference mode.

Validation of the model can thus be done by making use of reference modes and sensitivity analysis, to ensure that results obtained are logical and respond well to extreme changes in parameters. The model should respond logically to changes in initial conditions and changes in model boundaries.

PRELIMINARY FINDINGS

A brief qualitative description of the expected interactions and outcomes is given in this section and although the CLD is likely to expand as discussions and research continues, the model will be based on the broad framework as demonstrated in Figure 4.

Qualitative Description

It was previously discussed how the strength of SD lies in its ability to indicate stock and flows of resources and how it is influenced by auxiliaries and exogenous factors. Causal loop diagrams are used to reveal the dynamic process and indicate the chain of events affecting variables.

The CLD indicated in Figure 4 shows how the variables representing the population, fuel demand, biofuel demand and biofuel capacity influences one another. It can be seen how the causality of the birth and death rates in the Western Cape can be traced right through to the eventual biofuel capacity and feedstock requirements. A preliminary CLD was developed for commercial biofuel capacity expansion in the Western Cape which resulted in five balancing (B) and six reinforcing (R) loops in the highly aggregated CLD. The causalities present in the system are briefly discussed below.

R1: Birth rate influences the births and an increase in births will lead to an increase in the population, an increased population will once again lead to more births. This is a reinforcing loop, as it can be seen that population would tend to infinity if no element causes it to decrease.

B1: The balancing feedback loop that makes up part of the population causality shows how death rate increases the deaths and an increase in deaths will oppositely effect the population (i.e. decrease population) and a decrease in population will then lead to a decrease in deaths assuming that the death rate stays constant.

Causality: In the CLD the population was linked to the transport need and it is indicated that an increase in population will lead to more people having to make use of transport (private, public and commercial). An increase in the need for transportation results in a higher total fuel demand. The growing population will also lead to an increased water demand and increased food demand (resulting in more land use).

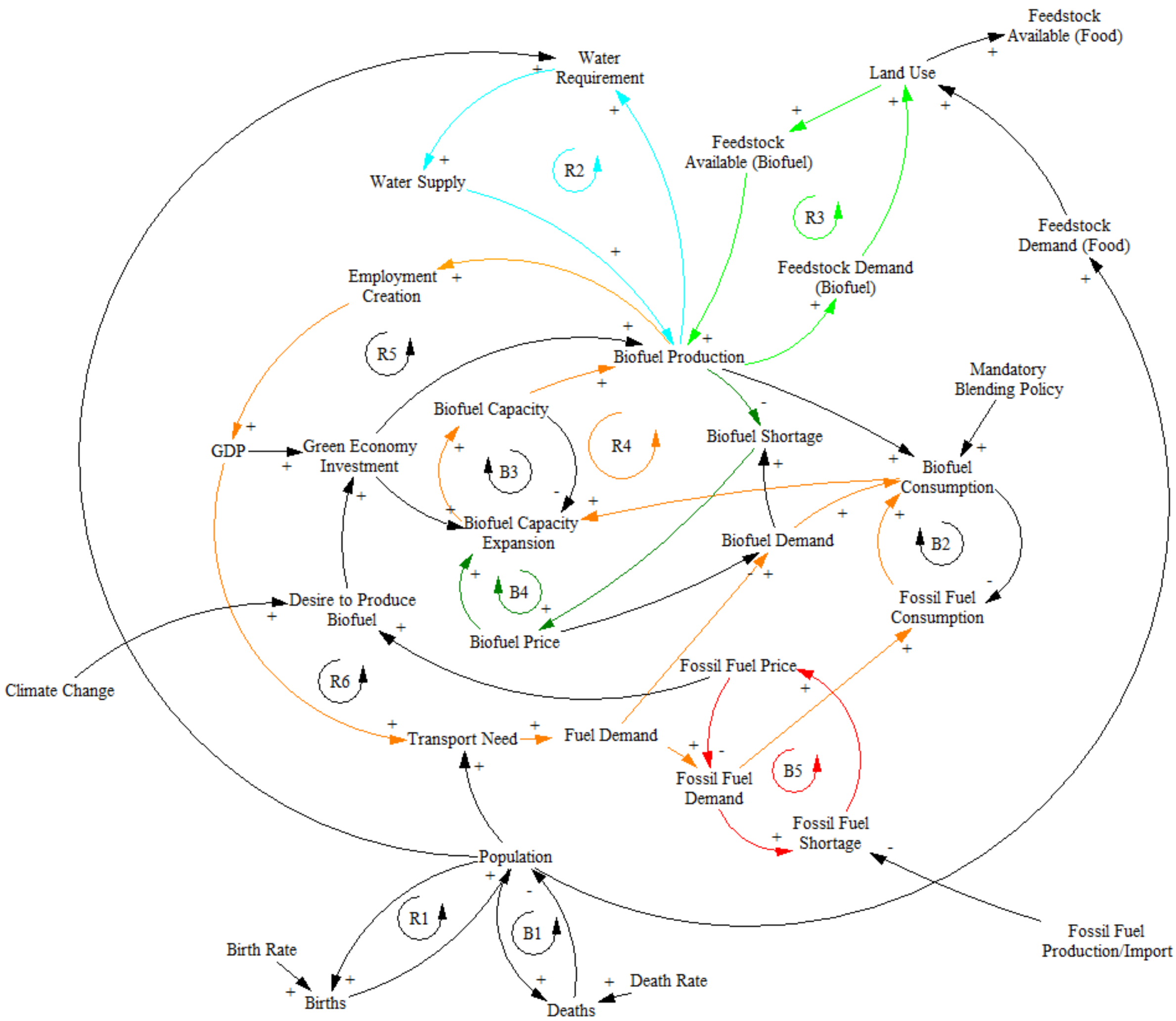

Figure 4: Causal Loop Diagram

Causality: It is shown that a higher fuel demand will lead to higher biofuel demand and consumption (based on the blending policy). Higher fuel demand also increases fossil fuel demand.

B2: The second balancing loop shows how higher biofuel demand will lead to higher biofuel consumption and ultimately an increase in biofuel consumption will lead to decreased fossil fuel consumption.

Causality: Increased biofuel consumption will lead to an increase in biofuel capacity expansion.

B3: An increase in biofuel capacity expansion will lead to an increase in biofuel production which will in turn lead to a decrease in biofuel shortage.

Causality: The increased biofuel demand will also increase the biofuel shortage.

B4: The increase in biofuel shortage will lead to increased biofuel price, which in turn increases the biofuel capacity expansion and follows B3 through to biofuel production.

R2: The second reinforcing loop shows how increased biofuel production will lead to increased water requirement and an increased water requirement will lead to more water being supplied, assuming it does not exceed the available water. If more water is supplied, more biofuel can be produced.

R3: This reinforcing loop shows how increased biofuel production will lead to increased biofuel feedstock demand and an increased feedstock demand will lead to more land being used, assuming it does not exceed the available land. More land being used for biofuel crop production will lead to increased available feedstock and more biofuel production. Note that land use is influenced by food- and biofuel feedstock demand.

R4: This loop shows how increased biofuel production will lead to increased employment creation and an increased GDP, which again increases the transport need, fuel demand, and biofuel demand and consumption. This loop reverts back to increase biofuel production through loop B3.

R5: The increase in GDP due to the increase in employment creation leads to increased capital available for investment into a green economy. The investment into a green economy leads to increased biofuel capacity being built and increased biofuel production.

R6: This is very similar to loop R4, and shows how the increase in biofuel production and employment creation eventually leads to increased fuel demand and then reverts back to biofuel production through loop B3 and B4.

B5: This loop shows how increased demand for fuel will increase the demand for fossil fuel, which in turn creates a fossil fuel shortage based on the fossil fuel production and imports. The shortage of fossil fuel will lead to an increase in price of fossil fuels and this will close the loop by decreasing the demand for fossil fuels due to the price increase.

Causality: An increase in fossil fuel prices will lead to an increased desire to produce biofuel as an alternative, which will see a larger investment into biofuels under the green economy. Climate change as an exogenous factor will also increase the desire to produce biofuel.

CONCLUSION

This paper identified the biofuel industry in the Western Cape to be a complex system with various intricate interrelations and dynamic interactions. This necessitated a review of methods to deal with complexity, which ultimately identified system dynamics to be the most appropriate method to model the commercial biofuel production potential of the Western Cape. Biofuel and some of the factors influencing decisions and policies regarding the various sectors involved was also briefly discussed and contextualised. Upon conclusion of this study, it will be possibly to analyse various scenarios and respective outcomes of commercially producing biofuel using triticale and canola as part of a transition to a green economy in the Western Cape.

The way forward

To successfully complete the research, a detailed system dynamic model will be constructed. The model will indicate all of the influential factors and drivers. The model outcome will give a good indication of what can be expected in terms of biofuel production potential.

A baseline scenario cannot be provided for biofuel, as there are no current operations. Different scenarios will however be modelled to investigate the impacts of the green economy investment and the biofuel production capacity expansion that will be required. An approach can be developed to minimise biofuel shortage and avoid the need to import biofuel to comply with the blending policies. The different scenarios that will be modelled and the exact system boundary will be finalised upon conclusion of discussions with various industry experts and will also consider previous work done in the biofuel sector in the Western Cape.

APPENDIX

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 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 vapour pressure) and an increase in emissions of acetaldehyde (which contributes to air and water pollution) (Balat et al. 2009).

Table 2 shows the three main groups and feedstock used to produce bioethanol with varying success. Numerous comparative studies have been done and triticale (a hybrid between wheat and rye) was found to be the favoured feedstock for bioethanol production based on its low nitrogen requirements, lower GHG emissions (in comparison to wheat) and high alcohol yields (Davis-Knight et al. 2008). Studies have identified that competing for land required for crop growth is one of the main concerns in bioethanol production. This makes triticale an especially strong feedstock contender in the Western Cape due to its high yield in nutrient deficient soils. This implies that it will be possible to grow the estimated required triticale yield of roughly 200 000 tons per annum in the marginal soil available within the WC, without anticipating serious adverse effects on other crop productions (Amigun et al. 2011).

Table 2: Bioethanol feedstock

Bioethanol groups	Feedstock
Sucrose containing	sugar cane sugar beet sweet sorghum fruits
Starchy materials	corn wheat rice potatoes cassava barley
Lignocellulosic biomass	wood straw grasses

Biodiesel is an attractive alternative to petroleum diesel fuel as it is biodegradable and non-toxic. Biodiesel is easy to produce and it can be manufactured from various fats and oils which can be obtained from animal and plant matter. Diesel engines were originally designed to run on vegetable oil, meaning that almost no conversion is required to run a diesel engine on biodiesel (Demirbaş 2002).

Table 3 shows the most common feedstock used for biodiesel production. The oils are sometimes used in their pure form but to improve on the environmental benefits, the used oil from other industries are more commonly used and converted into biodiesel (Ma et al. 1999). Based on the geographic and agricultural influences in the Western Cape, canola oil has been identified as the most feasible feedstock for biodiesel production. There is however little incentive for stakeholders to pursue this market, as biodiesel and canola oil has very similar market values, which doesn't justify the large investment required for biodiesel production (Meyer et al. 2008). In order to ensure an appealing business case for investors, subsidies will have to be implemented in order to convince role players to invest in this market and ensure biodiesel availability. There is also the additional concern of competitive markets drawing away from food production and land availability.

Table 3: Biodiesel feedstock

Biodiesel groups	Feedstock
Vegetable oils	corn
	cottonseed
	crambe
	peanut
	rapeseed
	soybean
	sunflower
Fatty acids	palm
	lard
	tallow
	coconut

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