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Establishing a new biofuel crop using Systems Thinking

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DECLARATION

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Abstract

The complexity of adopting a new crop-based biodiesel feedstock into South Africa given the prevailing environmental, economic and social concerns facing the country are addressed in this study by utilising a Systems Thinking approach.

Solaris is a new variety of Tobacco developed specifically as an energy crop over the last twelve years by Italian companies Plantechno and Sunchem. Small-scale trials have been underway over the last year in the Loskop Valley farming community in the Limpopo Province of South Africa. These trials have been managed by the newly-formed local entity, Toboil (Pty) Ltd.

In order to assess the viability of introducing Solaris into Loskop in terms of addressing the current diesel and electricity needs of the community and larger over-arching biofuel goals of South Africa, the full System Dynamic Modelling process was employed. This included significant research, stakeholder engagement, a Systems Thinking workshop as well as model development and simulation using the System Dynamics programming tool, Vensim.

Following the simulation of various scenarios, it was determined that in order for Solaris implementation to have the greatest impact on the diesel and electricity independence desires of the community, as well as maximising job creation and avoided greenhouse gas emissions, the first five to ten years of implementation may only achieve low to moderate profitability. It was further concluded that if crop-based biofuels are to help meet the rural development goals of South Africa then significant investment and skills transfer is required. In order to address both of these, a modular development process is advocated and should be aided and mentored by members of the commercial farming industry.

Opsomming

Die kompleksiteit van die aanvaarding van ‘n nuwe oes-gebaseerde bio diesel roumateriaal in Suid-Afrika in die heersende omgewings-, ekonomiese- en sosiale kommer wat die land ervaar, word in hierdie studie aangespreek deur gebruik te maak van ‘n Sistemiese Denke Benadering (Systems Thinking approach)

Solaris is ‘n nuwe variasie Tabak wat deur twee Italiaanse maatskappye Plantechno en Sunchem oor die afgelope twaalf jaar spesifiek as ‘n bron van energie ontwikkel is. Kleinskaalse proewe is gedurende die afgelope jaar in die Loskop Vallei Landbougemeenskap in die Limpopo-provinsie van Suid-Afrika gedoen. Hierdie proewe word onder die toesig van die nuut gevormde plaaslike entiteit, Toboil (Pty) Ltd uitgevoer.

Aansienlike navorsing, die aktiewe deelname van die onderskeie belanghebbende partye, ‘n Sistemiese Denke werkswinkel sowel as die ontwerp van ‘n simulasie model deur die gebruik van Sisteem Dinamieke Programerings program, naamlik Vensim, is ingespan om die lewensvatbaarheid van die moontlike aanplanting van Solaris te beoordeel. Die spesifieke gemeenskap se huidige behoeftes aan diesel en elektrisiteit sowel as Suid-Afrika se breër doelwitte aangaande bio-brandstowwe was as die grondslag gebruik waarop die volle Sistemiese Denke Benadering toegepas is.

In Loskop omgewing was verskeie moontlike scenarios beproef en daar is op grond daarvan vasgestel dat ten einde die grootste moontlike inpak te maak op die afhanlikheid van diesel en elektrisiteit behoeftes van die gemeenskap, sowel as om die grootste moontlik werkskepping potensiaal te verwesenlik – terwyl die afskeiding van kweekhuis gasse verhoed word - die eerste vyf tot tien jaar van implementering baie lae winsgrens tot gevolg sal hê.

Daar is ook verder afgelei dat afsienbare beleggings en opleiding benodig gaan word indien aangeplante bio-brandstowwe aangewend sou word om die landelike ontwikkelingsdoelwitte in Suid-Afrika te verwesenlik. Ten einde beide hierdie doelwitte aan te spreek, word ‘n modulêre ontwikkelings proses aanbeveel waar gevestigde lede van die kommersiële lanbou industrie, bystand en leierskap voorsien.

Acknowledgements

I would like to acknowledge the many contributors who enabled this project to go forward. Firstly, I would like to thank Blue World Carbon (Pty) Ltd and Toboil (Pty) Ltd for their financial contributions in funding the coursework and research avenues of this degree with Stellenbosch University. I would also like to thank my supervisors, Prof J.L van Niekerk and Dr L De Lange for directing me to the field of Systems Thinking as a means of exploring the subject of the study and coaching me through the process. Engagement with Prof A Brent and Dr J Musango during and subsequent to the System Dynamics module at the Sustainability Institute was invaluable for introducing me and encouraging me the field of Systems Thinking as well as with the use of the modelling software. In addition to those mentioned above I would also like to thank the rest of the attendees of the mini Systems Thinking workshop, particularly those from the CSIR Stellenbosch. Further, I would like to acknowledge the support of my friends, family and work colleagues as I endeavoured to perform the required research, modelling and writing-up of this report whilst also attempting to maintain some level of sanity with regards to full-time employment!

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1. Introduction

The agricultural system of South Africa has a variety of inter-linkages that relate not only to the food security of its citizens but also to employment, economic growth and the environmental sustainability of the nation as a whole. The term 'complexity', in general use, is used to describe something with many parts having an intricate arrangement. Due to this, the behaviour of an agricultural system can easily be viewed as complex. Further, given the challenges facing our world today with regards to increasing population, limited resources, climate change and political turmoil it can be safely assumed that the complexity of the system will increase.

When it comes to resource limits and the movement towards alternative or renewable resources and technologies, particularly those that involve the agriculture industry, it is not only the benefit of the acquisition of the resource that must be considered. The full impact of the acquisition of the resource along its entire value chain must be determined. For example, the resource use and greenhouse gas emissions of cultivating a biofuel crop needs to be compared against a "business as usual" petroleum-based fuel approach in order to understand whether its implementation is achieving the desired goals of sustainability and not being masked as viable due to a mandated or subsidised implementation.

This report is a study of the possible effects of introducing a new crop-based feedstock into South Africa for biodiesel and biogas production. The farming community of the Loskop valley is used as a specific case study for its implementation, and System Dynamic Modelling as the methodology of assessment. This is set against the backdrop of the current views of the South African Government with regard to implementing a national biofuel blending mandate.

Organised technology assessment as a formal procedure aims to predict the unintended negative consequences of implementing a new technology or innovation such that policy-making can be assisted (J.K. Musango, 2012). The central principle of this type of assessment is that it should reveal possible future outcomes of a new technology that may not have been foreseen. Specifically with regards to renewable and clean-technology development it has been identified as critical to study their possible implementation as complex systems. This is especially the case given the need to assess renewable and clean–technologies based on assumptions being made about sustainable development. Given that sustainable development is an interdisciplinary field incorporating economic, social, environmental and institutional changes, the use of System Dynamics for the kind of assessment required in this study has thus been advocated.

The purpose of using System Dynamics in this study is twofold. Firstly, it is a means of assessing the impact, uptake and viability of this new biofuel crop. Secondly, System Dynamics can be helpful in avoiding the pitfalls of similar failed initiatives. Predicting possible future pitfalls can stop the mass roll-out of an unsuitable crop but can also assist in structuring the implementation of a favourable crop in a sustainable way such that its potential is not overshadowed by a poor adoption strategy. Further, and particularly in this case where the biofuel crop is versatile, System Dynamics can assist in optimising adoption as various usage scenarios can be modelled.

This study will begin by defining the field of Systems Thinking and System Dynamic Modelling. It will then continue by giving the context of biofuels in South Africa by detailing its background in this country, the strategy and motivations of the government as well as potential areas of concern. The background and description of the novel biofuel crop, Solaris, being considered for implementation will then be discussed before an overview of the characteristics of other biodiesel crop types is given.

To contrast the System Dynamics assessment of Solaris, a case study of the contentious biodiesel crop Jatropha will be given. The focus will then be narrowed to the Loskop Valley farming community in Limpopo where Solaris trials are being conducted and various needs in the community have been identified. Based on interactions with local stakeholders, the reasoning and development of the Loskop Solaris System Dynamics model will be presented.

After a few iterations of model development and simulation using Vensim (a System Dynamics modelling program), a mini System Dynamics workshop was held in Stellenbosch to further engage relevant individuals in business and academia to assist in the model structure. The outcomes of this workshop will be discussed as well as how it influenced the further development of the model and which scenarios were considered valuable to incorporate. Following this, results from the various scenarios simulated will be presented. Lastly conclusions will be drawn and ideas for future work discussed.

2. Systems Thinking and System Dynamic Modelling

Before attempting to describe why and how a Systems Thinking framework was utilised for this study, it is necessary to briefly define and explain a few key concepts regarding this particular field of knowledge.

2.1.What is Systems Thinking?

As a precursor to defining System Thinking and System Dynamics, at the basic level let it first be stated what is meant by a system. For the purposes discussed here, a system can be described as an interconnection of parts functioning as whole, defined within a boundary (Musango, 2013).

Systems Thinking has thus been described as a scientific field of knowledge which uses the study of dynamic cause and effect over a period of time to enable understanding change and complexity within a system (K.E. Maani, 2007).

There are three separate dimensions to Systems Thinking (K.E. Maani, 2007). The **first dimension** is to do with a particular way of seeing or thinking about the world and interactions. This includes *forecast* or “big picture” thinking, *dynamic* thinking – i.e. given that systems are in constant motion; *operational* thinking – i.e. to do with considering the real interactions and physics in a system; as well as *closed loop* “circular” thinking – i.e. allowing one to consider how the outcomes of system behaviour may be what is driving the system to behave that way.

The **second dimension** is the specific language developed by Systems Thinking which aids in communicating system behaviour and complexity, often through the use of diagrams and particular rules of communication.

The **third dimension** is the specific methodology of developing models and group engagement so that the structure, interconnectedness and behaviour of a system over time can be understood. It involves the use of *causal loop diagrams*, *stock and flow maps*, *computational simulation* and *facilitated workshops* with key system stakeholders.

2.2.What is System Dynamics?

System Dynamics is defined as a trans-disciplinary and interdisciplinary method developed around the concept of system structures and is used to characterise complex systems by evaluating their dynamic behaviour over time (J.K. Musango, 2012)

From the **third dimension** of Systems Thinking, spoken of in section 2.1 above, System Dynamics is a computer simulation methodology used as a tool so that various scenarios of system behaviour can be analysed over a designated time period. Models are initially developed with the use of causal loop diagrams and these are then translated into stock and flow diagrams which can be programmed into specific System Dynamics software, like Vensim. Such simulation is only useful insofar as realistic relationships between system elements can be described with the acquisition of real-world data as well as meaningful engagement with relevant stakeholders to enable understanding of what the interconnections are as well as their strength of influence.

2.3.What are causal loop diagrams?

A causal loop diagram (CLD) is a tool for revealing the connecting relationships among a set of variables functioning together in a system (K.E. Maani, 2007). The elementary components of CLDs are variables and arrows, also known as links. In terms of CLDs, a variable is defined as a situation, condition, decision or action that can influence, and can be influenced by, other variables. They can be measurable (quantitative) such as profit, expenses and crop yield, or else they be more intangible in nature (qualitative) such as trust, reputation and motivation. Thus, CLDs allow for the incorporation of quantitative and qualitative variables, which is one of the strengths of the Systems Thinking approach. Arrows, the second component of CLDs, specify what the causal association between two variables is. Variables can be related in one of two ways. Either, they move in the same direction (i.e. an increase in one variable causes an increase in the other) or the opposite direction (i.e. an increase in one variable causes a decrease in the other). A CLD also displays how these "same" and "opposite" relations in a system can feedback on themselves. If a variable causes another variable to increase and this in turn causes the original variable to increase again, it is known as a positive reinforcing feedback loop. On the other hand, if a variable causes another variable to increase and this then serves to cause the original variable to decrease, it is known as a balancing feedback loop. A CLD describes these relationships for a certain circumstance, however if different assumptions are made the definition of the arrow, and hence feedback loop, can change. The example CLD displayed in Figure 1 below shows how a system of earning and spending can play out with its respective feedback loops.

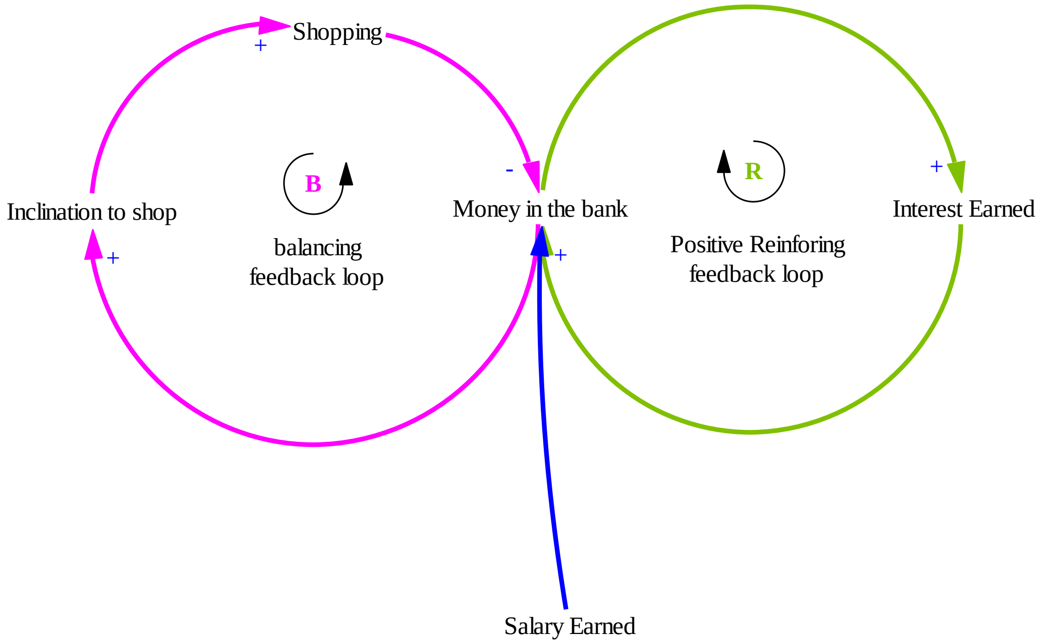

Figure 1: An example CLD demonstrating Reinforcing and Balancing feedback loops

2.4. What are stock and flows and auxiliary variables?

The crucial part of a System Dynamics model is the manner in which the system under consideration is being described in terms of stocks and flows (K.E. Maani, 2007). Stocks (also known as levels) are defined as being accrued quantities within the system such as population, cash, number of cows, etc. The state of a system is defined according to the stocks. A stock continues to exist even if any or all of the flows are brought to a stop. In the System Dynamics modelling package Vensim, a stock looks like:

Figure 2: Representation of a "Stock" in Vensim

Flows (also known as rates) describe how a stock will change over a period of time such as monthly revenue, interest on bank account value, births per year, etc. Flows can be governed by a variety of factors internal or external to a system (they can even be governed by the level of the stock itself) and their effect is demonstrated by observing the levels of the associated stocks. In Vensim, flows look like:

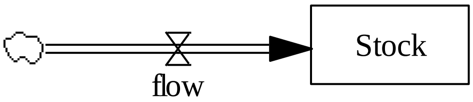

Figure 3: Representation of a connected "Stock" and "Flow" in Vensim

Auxiliary variables are a range of other types of variables (including constants, graphically defined relationships and other relationships that may change over time). Auxiliary variables allow for clarity and simplification of the model so that the flows are not required to contain complex relationship definitions. The stock and flow diagram below, based on the CLD example of Figure 1 above, illustrates:

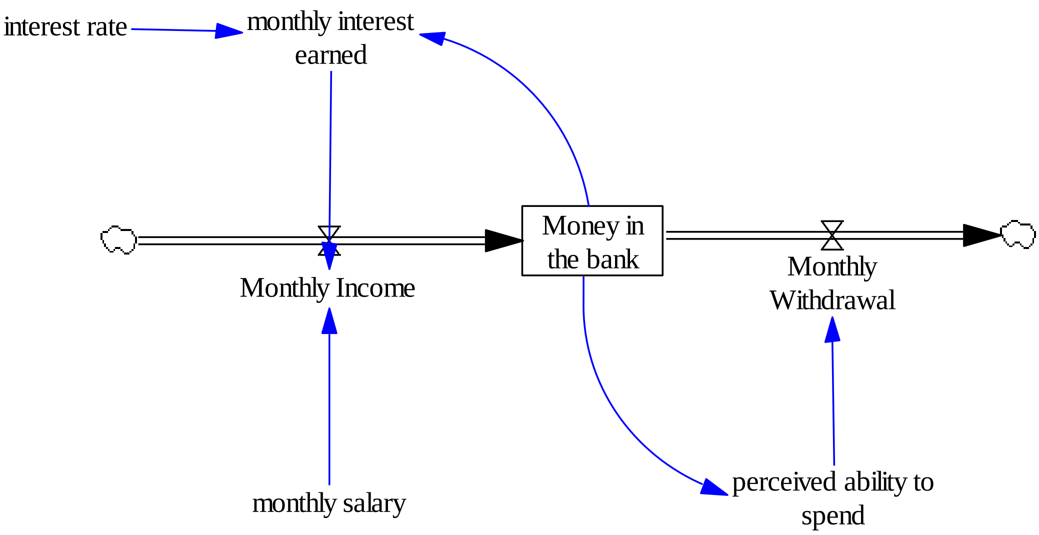

Figure 4: Stock and Flow Diagram based on the CLD example from Figure 1

2.5. Why is Systems Thinking and System Dynamic Modelling valuable?

Given the increasing complexity in the world as well as the inter-disciplinary nature of many organisations, structures, technologies and fields of academic pursuit, the utilisation of Systems Thinking and System Dynamics has been advocated (Musango, 2013).

A System Dynamics model can demonstrate dynamic changes, feedback, delays and other developments of a system. It is defined by its ability to quantify behaviour and associations as well as the degree of influence that particular elements in the system are able to wield. As a result of this, there are distinct benefits in observing, adjusting and managing a system over a certain period of time (F.J Li, 2012).

Further, given that one of the outcomes of this report will be to demonstrate whether Systems Thinking and System Dynamic Modelling is necessary for assessing the viability of introducing a new biofuel feedstock into the country, this study itself will demonstrate whether there is value to be added by these methods.

3. Biofuels in South Africa

The System Dynamics model that will be developed in this study is to do with the effect of implementing a new crop-based biofuel feedstock in a particular agricultural community in South Africa. However, to understand the relevance of a variety of elements in the system as well as certain factors driving behaviour, it is important to provide a bigger picture background of biofuels in South Africa as a whole.

3.1. A brief history of crop-based biofuels in South Africa

Over the past thirty to forty years, two types of renewable fuels, biodiesel and ethanol, have been determined to be possible to produce locally. Specifically biodiesel was considered as a replacement for diesel in agriculture. According to Frans Hugo, South African Biodiesel Director, this largely spurned out of the fuel crisis of 1979 which became so acute that South African farmers were unable to buy the fuel required to cultivate as much land as they had intended. This left South Africa vulnerable not only on the front of transport-fuel but also in terms of a possible food crisis had the situation persisted. Thus, there was an incentive for engineers locally to experiment with plant oils, particularly sunflower, to understand to what extent they could replace diesel fuel (Cameron, 2008).

Hugo’s team determined that since one hectare of sunflowers could produce 600 litres of sunflower oil, a one hundred hectare farm could produce enough fuel from ten hectares thereof to plough and plant the entire farm. The success of the sunflower biodiesel venture was proven though the tests and developments implemented, however, by 1985 all urgency of driving the process forward dissipated as the fuel crisis came to an end. Largely, it is the price of seed oils that made biodiesel ventures not worth exploring. Hugo determined that 20% of local diesel needs could be met from crops without affecting food security. He further stated that this 20%, interestingly enough, is also the amount required for agriculture in South Africa. Hugo believes that biofuels should not only be considered for energy security, but also as an opportunity for developing Africa's rural economies through moving away from subsistence farming and toward commercial farming, especially in Sub-Saharan Africa where he believes some of the worlds' largest biodiesel potential resides. Further, as is generally the case with biodiesel crops, a high protein press-cake remains after the oil is extracted. Due to this, biodiesel crops can be seen as contributing to food security through the avenue of animal feed, as opposed to completely detracting from it.

Following the decline of interest after the normalising of the fuel crisis of the late 1970's, biodiesel production in South Africa has largely been due to small-scale manufacturers, and that, largely utilising used cooking oil as a feedstock. No major investment into biodiesel production was deemed worthwhile given issues of the reliability of feedstock supply and oil price volatility. The next major development in biofuels in South Africa came in 2007 when the government released its biofuels industrial strategy. This will now be discussed.

3.2. Overview of 2007 South African Biofuels Strategy

The South African Biofuels Industrial Strategy of 2007 states that a biofuels programme will attract investment into the rural regions of the country, will promote agricultural development, result in a lower requirement of foreign fuel imports and have an equalising effect on distortions currently seen in trade between developing and developed countries due to the latter having subsidised agricultural production (Dept of Minerals and Energy, 2007). The strategy has a specific focus on creating jobs in underdeveloped regions like the former homelands, where previous inequalities have had a negative effect on agriculture there.

The Strategy specified a five year plan for a target of 2% penetration of biofuels into the county's fuel mix, which amounts to roughly 400 million litres per year, and particularly looking at the crop development of sunflower, canola and soya beans for biodiesel. Food security concerns have currently removed Maize and Jatropha as crop options for biofuel.The strategy states that this 2% target will amount to 1.4% of the arable land in South Africa, where 14% is currently being under-utilised. It has been identified that this under-utilised portion is largely located in the former homeland regions in the country.

Further, the strategy acknowledges the need for government assistance if its development goals of under-utilised land and previously disadvantaged inhabitants are to be reached and if those initiatives are then able to compete at a commercial scale. There is also recognition that biofuel refinery cooperatives in those regions would need to be encouraged. There is a proposed increase in fuel levy exemption to 50% for biodiesel in the strategy as well as support from existing agricultural programmes.

While the strategy mentions the possible emissions benefits of a biofuels programme its motivation for implementation is largely to do with job creation in the value chain of energy crops in the former homelands as well as how it can assist in forming a bridge between the first and second economies (Dept of Minerals and Energy, 2007).

The strategy however, imposed no mandatory blending regulations and hence little has changed in the industry since then. The most recent developments are as follows.

3.3. Updates in South Africa since the 2007 Biofuels Strategy

The 2007 Industrial Biofuels Strategy imposed no mandatory blending regulations and this is partly why investments in the industry to-date have been fairly modest (Prof. W.H. van Zyl, 2009). In August 2012 the South African Government Gazetted mandatory blending regulations for petroleum manufacturers, however an implementation date was not set (Department of Energy, 2012). There have been indications by the Department of Energy recently that October 2015 is when blending will finally become mandatory (Fin24, 2013). However, given the current state of the industry, whether these targets can be realised remains to be seen.

3.4. Concerns and opportunities for biofuels in South Africa

There are significant barriers for entrepreneurs involving themselves in the fledgling biofuels industry in South Africa (J.K. Musango, 2012). These barriers are: the cost of feedstock and security of supply, uptake in a volatile oil-price market (especially without implemented mandatory blending) as well as ensuring the specifications of the oil required by petrochemical industries.

Even with mandatory blending however, it seems biofuel feedstocks still need to be competitive with other crops that farmers could grow. Conversely, since commercial farmers are able to cultivate crops based on the income they can receive, food security cannot be overlooked in the instance whereby crops for biofuels are able to earn substantial returns. However, it must be remembered that fuel supply restrictions can have a direct impact on food security, as discussed in section 3.1, and thus, in the case of agriculturally derived biofuels, a balance must be reached.

Nonetheless, if the primary goal of the South African government with regards to biofuels is rural development, but the introduction of biofuel cultivation is only regarded as a "cash-crop" for commercial farmers, then hierarchical land and labour relations may continue to be entrenched, trapping labourers in maintaining subordinate relationships without acquiring any benefits from the crops they grow (Banda, 2008).

Further, if the greening of South Africa's resource use is in any way a goal of local biofuel adoption, then an assessment of the global warming potential (GWP) of the full life cycle of the particular biofuel crops under consideration must be determined. Through full life cycle analysis is has been determined that a significant reduction in

GWP by utilising a crop-based biodiesel feedstock could only be achieved when a biodiesel crop is not grown on newly cultivated land and does not require substantial irrigation (A.L Stephenson, 2010). Thus, the type of land allocation and resources used are paramount for consideration in the South African biofuels context.

In summary, sustainably implementing the blending goals of the South African biofuels mandate necessitates a well-established biofuels industry. A well-established biofuels industry however, seems to necessitate (barring a substantial cash injection from the state) the significant involvement of commercial farmers. However, directing the industry largely towards commercial farmers could be problematic in terms of meeting the desired rural development goals of the country in the mandate. Further, secondary goals of climate change avoidance need to be considered in the full life-cycle of the implementation of any biofuel crop. Hence, a viable crop, grown in a sustainable way, that can meet the blending goals of the mandate (and much more if necessary) whilst also meeting its socioeconomic goals is required.

Thus, via the avenue of System Dynamic Modelling, part of this study's aims will also be to consider the viability of a new feedstock not only in terms of yield and resource use, but also in terms of its manner of implementation such that it can be sustainable as well as contribute to the development goals of South Africa

4. Tobacco Solaris

The new biofuel feedstock being considered in this study has been developed over a number of years in Italy and trialled in a variety of countries. Before the specific region where trials in South Africa have begun is discussed, an overview of the crop's background and characteristics will be given.

4.1. The background of Tobacco Solaris

Fifteen years ago an Italian plant-based biotechnology company, Plantechno, identified that certain characteristics of the Tobacco plant gave it incredible potential to be developed into an energy crop (C. Fogher, 2011). These characteristics include:

- Its status as a non-food crop
- Its ability to grow on marginal lands, less unsuitable for food production (as with Classic Tobacco) (Norscia, 2013)
- Its seeds having approximately 40% oil (C. Fogher, 2011)

In the years following, Plantechno has selected some varieties with maximised seed production, minimised leaf production and negligible nicotine content. They patented this "Seed Tobacco" and collaborated with another company, Sunchem, to develop the industrial application of this new energy crop.

Based on trials conducted in Italy, Brazil, North Africa, Bulgaria and the USA, average production yields per year, assuming 40 000 to 60 000 plants per hectare, are as follows (C. Fogher, 2011):

- 2.5-5 tons of seed per hectare per harvest(seed per plant in range 50g-100g)
- 15 tons dry biomass (leaves and stems) as residual after harvest, or
- 1.5kg per plant of wet biomass (thus 60-90 tons per hectare per harvest) if the whole plant harvested for a biomass application

Depending on the pedo-climatic situation of the site in question, between 2 and 5 harvests (with an average of 3) per season have also been witnessed. Figure 5 demonstrates the typical cycles of sowing, transplanting and harvesting of Solaris.

4.2.Cultivation and processing information

The resulting products and applications of the cultivation of Tobacco Solaris are:
- Utilising a screw press, 33% oil can be extracted from the seed (suitable to be processed into bio-diesel or bio-jetfuel) (Norscia, 2013)
- A residual oil cake with a calorific value of 4.618 Kcal/kg, 35% protein and high in linoleic acid (suitable for use as an animal feed aggregate)
- If the entire harvest is used as biomass, 273.7 m^3 of biogas per ton of biomass (suitable for use in electricity generation) (C. Fogher, 2011)

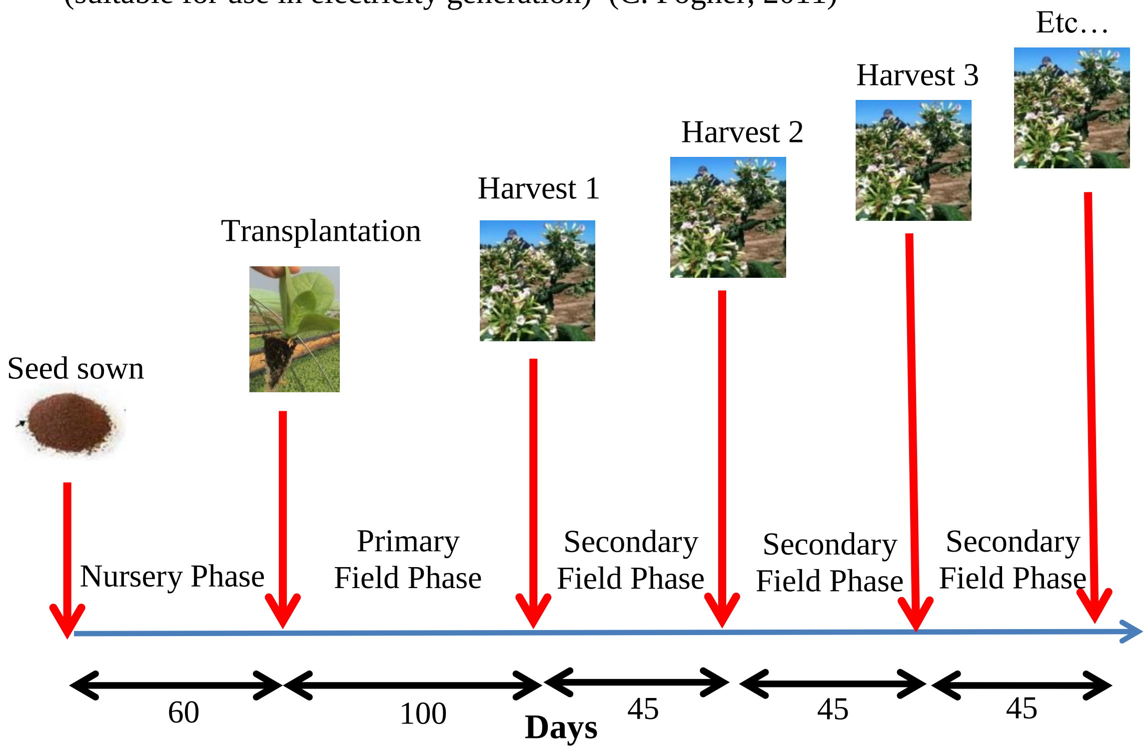

Figure 5: Diagrammatic representation of a typical growth and harvest cycle of Solaris

5. Other biodiesel crop-based feedstocks

Another important matter for consideration when introducing a biodiesel crop into a region is how well the crop of choice compares to other similar crops. This is not only critical in terms of yield per hectare, but also in terms of resource use, global warming potential, cost per hectare and difficulty of cultivation. Also relevant for this study is considering the impact that other crop-based biodiesel feedstocks have made on a system. Other possible options of local biodiesel crops will now be compared in terms of yield and other environmental effects. Following this, the specific case study of Jatropha curcas will be discussed given that attempts have been made to introduce it globally as new biodiesel feedstock in recent years.

5.1. Biodiesel Crop Yields

The South African Biofuels Industrial Strategy of 2007 mentions sunflower, canola and soya as the primary candidates for biodiesel production (Dept of Minerals and Energy, 2007). Due to this it seems relevant to compare their respective yields and oil contents with Tobacco Solaris as well as another controversial biodiesel feedstock that will also be discussed, Jatropha curcas. Table 1 below displays a comparison of seed and oil yields as per international averages, whilst Table 2 displays a comparison of seed yields from South African cultivation in the 2006/2007 season.

Table 1: A comparison of average yields and oil potential in a selection of biodiesel feedstocks (international values)

Crop	Seed yield – international averages [a] (ton/ha)	Oil content of seeds (%)	Extractable Oil yield (L/ha)*
Canola (Rape Seed)[a]	3.3	33.2-47.6	965-1250
Sunflower[a]	1.9	32-45	534-742
Soyabean[a]	1.5-3.3	21-22	274-635
Jatropha curcas[b]	1.5-2	25-40	540-680**
Tobacco Solaris[a]	5.7	39-41	1930-2038

*assuming 80% extraction efficiency

**claims of up to 1890 L/ha (Fitzgerald, 2006)

a- taken from (C. Fogher, 2011), **b**- taken from (Darr, 2007)

Table 2: A comparison of average yields in South Africa from 2006/2007

Crop	Seed yield – RSA averages[c] (ton/ha)
Canola (Rape Seed)	1.5
Sunflower	0.95
Soyabean	1.2

c- taken from (A.L Stephenson, 2010)

5.2. Factors affecting the global warming potential (GWP) and resource use of biofuel crops

Specifically with regards to the biodiesel crops canola, soybean and sunflower, it has been determined that the GWP and fossil energy requirement during their cultivation depends largely on crop yields, the requirement for irrigation and whether the land being ploughed has been previously cultivated or not (A.L Stephenson, 2010).

Whilst canola and sunflower crops have the potential to produce more biodiesel than soybean due to their higher oil content, other factors relating to the climate of the region and the type of land utilised play a role in determining which crop is best suited for a particular region. Each of the main factors affecting GWP and resource use will now be discussed.

5.2.1. Direct land-use change

For the production of biodiesel it is important to understand whether the land used for cultivation has been used for cultivation before, and if not, whether it would have otherwise been left uncultivated. This is important because changing uncultivated land to fully utilised arable land causes the carbon content of the soil to decay at an exponential rate over a 10-20 year period, thus releasing significant amounts of carbon into the atmosphere (A.L Stephenson, 2010). Using guidelines from the Intergovernmental Panel on Climate Change, the effect of converting grassland to cultivated land can be assumed to result in CO_2 emissions of 18 tons per hectare.

In relation to the type of land to be used in South Africa for biofuel production, the 2007 Biofuel Strategy aims to grow biofuel crops on land that is classed as “under-utilised but with high potential”. This land is largely the former homeland regions of South Africa (Dept of Minerals and Energy, 2007) and is mostly grassland and woody savannah. The Strategy doesn’t specify what portion of this under-utilised land is already being used as farmland but it is known that a significant proportion thereof, which are grazing and grasslands, would need to be specifically cultivated such that an oilseed crop can be grown there (A.L Stephenson, 2010). The example given is of the Eastern Cape Province, where there are plans to use 250 000 hectares to grow canola and soybean on underdeveloped land specifically for biodiesel production. Of this land, over 95% is presently uncultivated. Thus assessing the effect of GWP of converting this land to arable land for biofuels must be performed.

5.2.2. Indirect land-use change

Even if currently utilised agricultural land is used for biodiesel crop production, indirect greenhouse gas emissions can be caused by its introduction if the current crops are displaced as a result. The displacement can result in increased production elsewhere or by importation of those commodities or by the use of alternative products. Due to this, there could be a significant environmental effect. A South African example, is that if grazing land is now being used for a bioenergy crop, that grazing will need to move elsewhere and thus result in further land use change with potential negative consequences (such as deforestation) (A.L Stephenson, 2010).

5.2.3. Nitrous oxide from soils

The production of nitrogenous fertilisers is energy-intensive and releases substantial quantities of nitrous oxide. Once in the soil, some of the nitrogen is converted to N_2O, a potent greenhouse gas, and is released into the atmosphere. Due to this, these fertilisers contribute to the GWP of biodiesel crops. The severity thereof depends on how much fertiliser is required per crop type (A.L Stephenson, 2010).

5.2.4. Irrigation and working the land

The effect on resource use and GWP of a particular biodiesel crop in terms of irrigation and working the land depends on the method and amount of irrigation and machine usage required. This is also balanced against the expected yields for that crop. In South Africa, if a central pivot system used for irrigation and is powered by electricity the GWP is higher than if powered by diesel due to the emissions associated with predominantly coal powered national electricity grid. Ploughing, fertilising and harvesting generally all require diesel if they are done by machine.

From the above sections it seems a balancing act must be performed in terms of comparing the yields of different biodiesel feedstocks in relation to their water and fossil-fuel resource requirements. If a crop is high yielding enough, it may be inconsequential that its GWP and resource use per hectare is higher than another biodiesel crop. However, irrespective of the crop used, cultivation on previously uncultivated land seems to be one of the most significant causes for concern in terms of the ultimate GWP of a biodiesel crop in relation to its petroleum counterpart.

5.3.The case study of Jatropha curcas

Given that this study is not to do with introducing a crop that has already been commercialised elsewhere into an area, but rather a new, potentially promising, variety, it is of interest to consider a case study of where another new or non-commercialised biodiesel crop has been introduced.

Jatropha curcas is a non-edible plant, originating in Central America that has become known for its ability to be used as a biodiesel feedstock. Jatropha is a perennial tree and produces seeds from its fruit that can be pressed for oil (K. Nahar, 2011). The attraction of Jatropha, which led it to be considered a "wonder" crop for biodiesel is to do with its claims of very high seed yields (reports of up to 1890 litres of oil per hectare) whilst being able to be grown on semi-arid, marginal lands without irrigation and much care and with a lifespan of around 20 years (P. Kant, 2011). This led to various countries looking to meet their biofuel blending needs by adopting this crop on a large scale. The Planning Commission of India decided in 2003 to introduce mandatory blending of biofuels over large parts of the country with a goal to reach 30% by 2020. Given the Commission's desire to utilise a high-producing biofuel crop, whilst making use of land unsuited for general agriculture, and also requiring minimal attention and irrigation, Jatropha was chosen as the major contributing feedstock. The scale of planting was extensive and schemes were created which attracted millions of marginal farmers and landless people to plant Jatropha across the country. A similar biofuel initiative in China led them to try raise over 1 million hectares of marginal lands for Jatropha. The trend continued in other developing countries by encouraging a multitude of small-scale farmers to grow Jatropha as a means of generating renewable energy for the country and increasing their incomes. Thousands of small farmers in Tanzania and other parts of East Africa also set up Jatropha plantations. Thus, by 2008 Jatropha had a global stake of 900 000 hectares and an expectation to reach 12.8 million hectares by 2015.

Implementation however, was a different story. Mandatory blending in India could not be enforced as production fell far short of the expectations and recently 85% of the Jatropha farmers have discontinued their cultivations (P. Kant, 2011). Further, at the time of reporting, China has also seen minimal production of biodiesel from Jatropha and largely unsatisfactory results have been seen in Tanzania also. The present value of the five year investment in Jatropha in Tanzania is running at a loss of US$65 per hectare (if 2 tons/ha of seed are yielded). Despite being renowned for oil production, seed production is affected when moisture and nutrition are lacking. The length of flowering season and number of flowering events per season, as well as seed size and content, is very much dependant on soil fertility, temperature and humidity. This means that from region to region the plant will behave differently.

It seems these countries decided to engage in a hefty implementation of Jatropha without an adequate trial phase or conducting an extensive due-diligence on its claims. It is apparent that despite the ability of crop to achieve good results in one place, varying pedo-climatic conditions need to be tested, as well as if the particular breed in question can be proven to produce consistent yields.

There are a number of lessons that can be learnt from the Jatropha incident. Firstly, governments should tread lightly when it comes to the large scale adoption of any crop that is new to the region. Without fully understanding the best manner of cultivation, climatic effects, soil types as well as local pests and diseases, a crop with great potential may be unduly discarded. Secondly, risking such large portions of land with an untested crop means that failure will be a costly exercise, particularly if a mandatory blending regulation has been imposed. Thirdly, the schemes that involved incentivising marginal or poorer farmers can result in a loss of livelihood for them if sustainable yields cannot be achieved. Additionally, if an initial roll-out is largely to marginal or peasant farmers it can also mean that there is inadequate training, knowledge transfer and support with regard to cultivating a new crop type. This can also lead to a crop with great potential being rejected for use, as well as result in a failure to meet mandated biofuel blending criteria. Fourthly, until all claims are thoroughly tested there should always be a level of scepticism about any "wonder" crop, particularly one that makes grandiose claims about negligible resource consumption. Lastly, and particularly for decisions made at a national level, an extensive due diligence on a new biofuel crop type must be conducted.

Based on the shortcomings of the attempts at implementing Jatropha, particularly with regard to all the unintended consequences, it seems that there perhaps could have been some benefit to have conducted a Systems Thinking or System Dynamic Modelling exercise. It is hoped that by doing so for the crop under consideration in this study that all of the negative outcomes of Jatropha can be avoided.

6. The Loskop Valley Farming Region

The region being considered for this study is the Loskop Valley, which lies between and around Marble Hall and Groblersdal in the Limpopo province of South Africa. Before describing the development of the Systems Dynamic model regarding the implementation of Solaris in the Loskop Valley, a brief background of the area and cultivation occurring there currently will be given. Following this, issues pertinent to the local community will be discussed as well as their current cultivation resource requirements and concerns. Lastly the reasoning behind the introduction of Solaris into the community will be described as well as the results of the small-scale trials that have already been conducted there over the last year.

6.1. The background of Loskop Valley

In 1938 the Loskop dam was completed and along with an extensive network of irrigation canals allowed for a thriving farming community to develop in the region surrounding it (WISA, 2008). As seen in Figure 6 around the towns of Marble Hall and Groblersdal exists 16 000 hectares of cultivated commercial irrigated land.

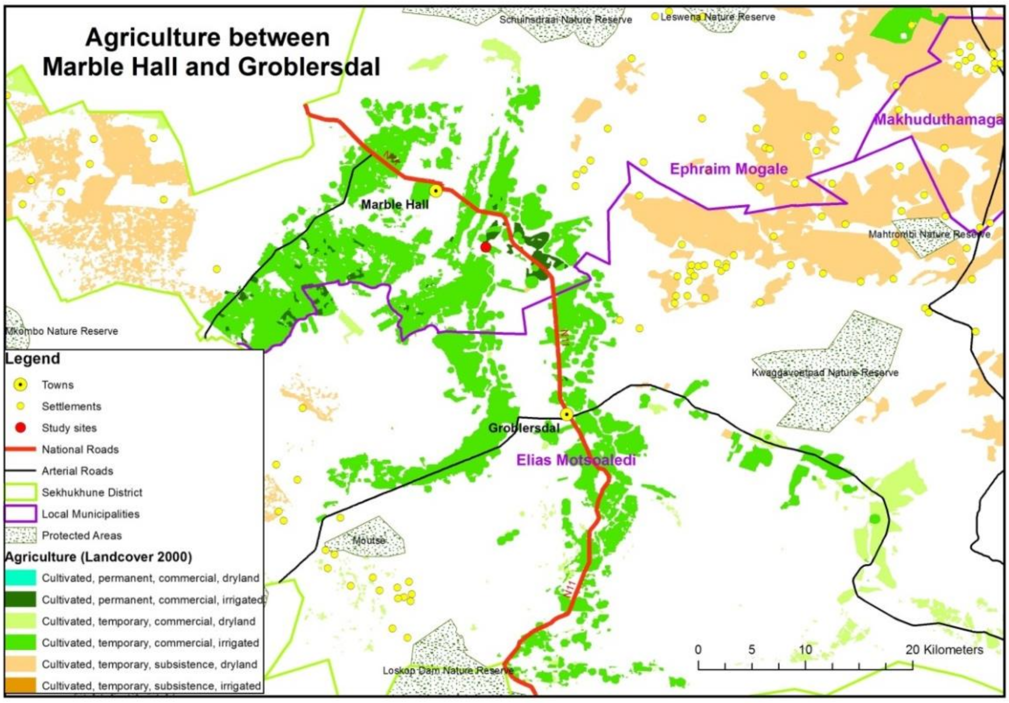

Figure 6: spatial map of the irrigated, cultivated, commercial land of the Loskop Valley (courtesy of the CSIR Stellenbosch)

6.2. The Classic Tobacco industry in South Africa and Loskop Valley

In the last 10 years, land used for Tobacco production in South Africa has decreased from 14 700 hectares to 5 400 hectares (TISA, 2006) and (DAFF, 2012), Table 3 below displays the trend. In the Loskop region, which has always boasted the largest Classic Tobacco production in the country, a similar decline has also been noted. Currently approximately 3 500 hectares are being planted yearly, whereas previously it was in excess of double that figure (Kok, 2013). However from discussions with the local Tobacco farmers it seems that this amount of land has now been kept constant over the last 3 years. This decline in Classic Tobacco land allocation in the country could have a variety of causes relating to cost of production, demand, or perception of smoking, however, it is largely attributed to the introduction and implementation of Tobacco control regulations between 2004-2008 (Directorate Marketing, 2011). All this seems to indicate that the Loskop Valley:

- is a very suitable region for growing Tobacco
- has ample farmers experienced in the cultivation of Tobacco
- potentially has a need for an alternative crop that experienced Tobacco farmers can cultivate, which may improve their position to negotiate with large Tobacco distributers or if control regulations are further tightened

Table 3: Classic Tobacco in South Africa, area planted and total production trends until 2011 - taken from (Directorate Marketing, 2011)

Year	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Area planted (ha)	14 700	13 600	11 500	9 200	6 000	6 000	3 400	3 600	4 000	5 400
Total produced (000 tons)	33.1	37.4	25.3	23.5	14.9	12.8	9.1	9.5	11.1	15.6

6.3. Current farming in the Loskop Valley

Table 4 below shows data, acquired from the Loskop Irrigation Board, about the range and hectare allocation of crops grown in 2012 on the irrigated commercial farmland displayed in Figure 6. Note that the total is well over 16 000 hectares since in many cases more than one crop can be grown in a yearly cycle (Ferreria, 2013).

6.4. Energy, economic and social concerns in the Loskop Valley

Interviews conducted with a number of farmers in the area have brought to light several concerns over energy security and cultivation profitability in the region. As mentioned by Frans Hugo in section 3.1, diesel and electricity is critical to current commercial farming practices. Additionally, their security of supply and price are of great concern for the continuation of economically viable cultivation. Further, substantial increases in the cost of fuel and electricity are affecting the ability of farmers to make a profit from certain crops.

As broken down in Table 4, a portion of the farmers grow permanent crops, such as grapes, citrus, olives, figs, nuts, etc. where the input costs and payback periods are high but as are the returns due to large scale export of most of their products. The rest of the farmers vary their crops seasonally according to the best price on the local market and deal with much lower margins and lower inset costs.

The permanent crop farmers expressed great concern over energy security being a possible limiting factor to their enterprises going forward (Borcher, 2013). One of the primary concerns is consistent electricity supply. Power cuts from Eskom limit the regulation of their cold-room temperatures and therefore have a dramatic effect on the shelf-life of their fruit in Europe and Asia. Further, the Loskop Valley agricultural zone has reached its line capacity with Eskom and thus any desires to expand on processing operations is restricted (Scheepers, 2013). Similarly, any issues with the supply of fuel going forward would cause similar hiccups for their time and temperature sensitive operations. However, these permanent crop farmers have ample capital to spend on energy investments in the area if it could help them become energy independent (Borcher, 2013).

Non-permanent crop farmers however, deal with much smaller margins. They would generally not want to engage in an activity where a return would only be seen 5-10 years later and would only be interested in an energy crop (or alternative energy solution) insofar as the crop itself directly provides them with a fairly immediate profit. Both types of farmers however, acknowledge the need for reasonably priced diesel and electricity for the continuation of their farming enterprises.

Lastly, the doubling of minimum wage in the last year has affected the employment and farming structures in the Loskop Valley. In order to continue being financially viable, some farmers have changed crop types or are considering mechanisation so that less labour is required. In a region where already there is a fair amount of unemployment and poverty, upliftment of the labour force is an obvious need.

6.5. Electricity and Diesel usage for Cultivation in Loskop

Based on an interview with the farm manager of Terblanche Boerdery in the Loskop Valley and the range of crops he has experience in cultivating in the region, diesel use required per hectare per season for the cultivation of each crop grown was obtained (Swanepoel, 2013). A further interview with a local Eskom representative, Werner Scheepers, in Groblersdal provided insight into the electricity usage required by each crop per season of irrigation (Scheepers, 2013). It is standard to assume the following for the irrigation of a particular crop type:

$$Electricity\ usage\ for\ crop\ x$$
$$= 1\ (kW)\ \times 365\ (day)\ \times 24\ \left(\frac{hour}{day}\right)\ \times load\ factor\ (\%)$$
$$= 365\ \times 24\ \times load\ factor\ crop\ x \quad (kWh)$$

The individual and cumulative usage of diesel and electricity in the Loskop Valley for cultivation can be seen in Table 4 below.

Table 4: Crop allocation, crop type, land size and diesel and electricity required for the cultivation thereof in Loskop

Crop	**Crop Type**	**Land Size**	**Diesel Use**	**Diesel Use**	**Elec Load factor for Irrigation**	**Irrigation Elec Use**
	Permanent or Non-Permanent		per Ha per season	Total per season	percentage	all land per season
		hectares	*litres*	*litres*		*kWh*
Wheat	Non-Permanent	7 664.5	77	590 166.5	17%	11 413 973.4
Peas	Non-Permanent	1 413.5	65	91 877.5	27%	3 343 210.2
Vegetables	Non-Permanent	1 593	65	103 545	27%	3 767 763.6
Tobacco	Non-Permanent	3 673	500	1 836 500	14%	4 504 567.2
Cotton	Non-Permanent	7 680.4	99	760 359.6	24%	16 147 273
Seed Maize	Non-Permanent	1 403.5	77	108 069.5	17%	20 90 092.2
Commerical Maize	Non-Permanent	2 816	77	216 832	17%	41 93 587.2
Citrus	Permanent	3 453.1	346	1 194 772.6	31%	9 377 238.4
Grapes	Permanent	739.5	305	225 547.5	31%	2 008 186.2
Other	Mix	917.5	80	73 400	28%	2 250 444
Peaches	Permanent	15	340	5 100	31%	40 734
Nuts (Macadamias)	Permanent	20	250	5 000	24%	42 048
Nuts (Pecans)	Permanent	76	250	19 000	24%	159 782.4
Granadillas	Permanent	5	250	1 250	31%	13 578
Olives	Permanent	23	250	5 750	31%	62 458.8
Figs	Non-Permanent	8	250	2 000	31%	21 724.8
Flowers	Non-Permanent	6	80	480	31%	16 293.6
Herbs	Non-Permanent	40	80	3 200	31%	10 8624
Lucern		38	77	2 926	0.41	136 480.8
TOTAL	**N/A**	**31 585**	**3 518**	**5 245 776.2**	**N/A**	**59 698 059.72**

6.6.Why the introduction of Solaris in the Loskop Valley

Given the suitability of the Loskop pedo-climatic conditions for Tobacco cultivation as well as the expertise with Tobacco in the area, it makes sense to begin local viability analysis in this region.

The current goals of the South African government with regard to the implementation of a biofuel blending mandate means that considering a crop that may surpass other biodiesel crop options in terms of yield, resource use as well as in versatility of function (oil, biogas, animal feed), can only be beneficial. This is particularly the case due to the (supposed) impending implementation of mandatory blending in October 2015 (Fin24, 2013). Though the mandate states that the focus is on previously disadvantaged homeland regions for rural development, it seems logical to develop and test a framework of biofuel crop adoption in an area supported by commercial farmers. If successful, this could allow the knowledge and experience gained to be replicated in those regions, perhaps with the assistance of commercial farmer mentorship.

Further, the energy and social concerns in the Loskop region provide a platform for ascertaining to what extent this crop, particularly if local processing plants are installed, can sustainably impact the energy independence and profitability of the area whilst also addressing the social inequalities that are being perpetuated due to current commercial farming practices. Seed pressing plants, biodiesel plants and biogas power generation plants could bring about significant social upliftment as it will necessitate additional employment and skills transfer

6.7. Trials already conducted with Solaris in Loskop

Though the Solaris Energy Tobacco trial in the Loskop Valley over the summer cultivation period of 2012-2013 was very small, there were some useful results about expected yields for both seed and biomass. These particular trials started 3 months later than they should have been, with associated issues, so results achieved for the single harvest obtained are thought to be fairly conservative. Nonetheless a brief overview of the process and results obtained will be given below.

Figure 7: Nursery phase of Solaris 2012-2013 Loskop preliminary trial (62 days spent in nursery)

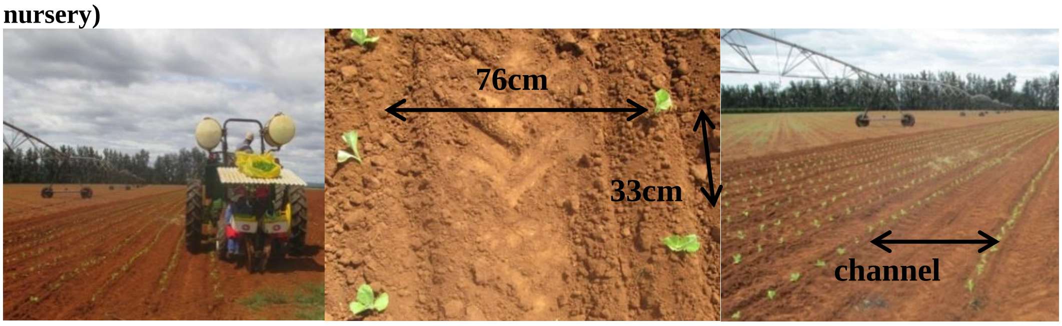

Figure 8: Transplantation of Solaris 2012-2013 Loskop preliminary trial (December 2012)

Figure 9: 21 days after transplantation of Solaris 2012-2013 Loskop preliminary trial

Figure 10: 39 days after transplantation of Solaris 2012-2013 Loskop preliminary trial showing early stages of flowing and seed capsules

Figure 7, 8, 9 and 10 display the cultivation progression from the nursery to the development and flowering of the inflorescences. Figure 11 shows a few sample inflorescences that were chosen to be harvested separately to ascertain the capability for seed production of a standard plant. Table 18 in Appendix C lists all the results and shows that the average seed yield for that particular batch taken was about 66g dried seed per plant. It should be noted that there were a number of plants which far exceeded this seed quota per harvest but were not selected for the standard sampling.

Figure 11: A few of the sample plants of Solaris 2012-2013 Loskop preliminary trial indicating the inflorescences

Thus, based on the results achieved in the preliminary trials, seed yields between 50-100 grams per plant per harvest can be expected. Similarly, a selection of full plants was also harvested such that an understanding of the wet biomass capability could be obtained. From Table 20 in Appendix C it can be seen that the average weight of the entire plant is around 1.52kg. Therefore biomass yields between 1-1.5 kg per plant per harvest can be expected. The trial also revealed that the diesel requirement of Solaris cultivation in comparison to Classic Tobacco is about 40% less.

The next, larger, trial phase is currently underway in Loskop. This phase was started at the correct time in the season and so it is hoped that a more accurate idea of the seed and biomass yields as well as number of harvests per season can be obtained.

7. The Loskop Biofuel System Dynamics Model

Based on all that has been described above, this chapter will serve to, firstly, justify the use of Systems Thinking and System Dynamic Modelling for considering the implementation of Solaris in Loskop, as well as the larger South African context. Following this, the System Dynamic Modelling process that was followed will be presented. Since one cannot model a whole system, this process begins with defining a particular problem to be solved within the system considered. After this the causal loop diagram (CLD) development will be presented as well as a description of all the stock and flow variables included in the model. Lastly, all the assumptions and real world data acquired will be explained and the baseline results given.

7.1. Why use Systems Thinking and System Dynamic Modelling for considering Solaris in Loskop and South Africa?

The above chapters have set the scene for the context of biofuel adoption in South Africa. On the one hand there is the desire for a sustainable biodiesel crop that can viably contribute to the country's fuel requirements as we move into a time of potential petroleum scarcity, or at least potential supply volatility. On the other hand there are very specific goals for biofuel adoption from the South African government relating to rural development and social upliftment of many of its citizens. Further, the backlash effects of fuel and electricity price hikes and supply inconsistencies on the current viability of agriculture in South Africa are being called into question. Additionally, as the national biofuel goals are moving from being theoretical to mandated, there are wider concerns about the impact on food security and the environment in comparison to using petroleum based fuels.

The inter-relatedness and apparent complexity of all of these issues speaks directly to the interdisciplinary approach that Systems Thinking and System Dynamic Modelling uses. This specifically with regards to enabling understanding of the system as well as aid in decision making when there are so many influencing factors. Further, certain case-studies like that of Jatropha, spoken of in Section 5.3, demonstrate the need to understand the full systemic impact of introducing a new crop-based biofuel feedstock into a region. This is particularly important where there are risks of large financial losses, loss of livelihood and environmental degradation.

Given that small Solaris trials began in the Loskop farming community in 2012 and that larger phase 2 trials are currently underway for the 2013-2014 season, it makes sense to consider this region as a closed system for modelling this new biodiesel feedstock. Closing this system also makes sense given the community's needs and concerns over rising energy costs and security.

The benefit that a local high-yielding biodiesel crop can have on the Loskop farming community's energy needs and economic sustainability seem obvious, especially if one can replace a portion of the classic leaf Tobacco which has such a wide-spread negative reputation. However, there are potential risks and thus associated negative consequences to its incorrect implementation and thus it is imperative that a systemic model be built to analyse its adoption in the region. It is important in building this model to identify any risks and possible resulting consequences as well as the predominant controlling factors. Doing so will enable the best possible implementation plan, else the project could be banned in its entirety. The model needs to be able to dynamically and quantitively simulate a reasonable adoption of the energy Tobacco within this particular farming community given the prevailing attitudes, revenue expectations and requirements of fuel processing setup. Accessing the viability in terms of farmer profitability as well as environmental effects and the larger socio-economic goals of the country is important.

7.2. Problem Definition

There are fuel and electricity concerns in the Loskop farming community. Both diesel and electricity costs are continuously on the rise as well as there being concerns over security of supply. Within the agricultural district the Eskom line capacity has been reached and at this stage there are no plans to increase it (Scheepers, 2013). Particularly for export related crops that rely on maintaining the cold chain to ensure shelf life and hence revenue, unpredictable power cuts mean that the development of energy independence is key for those producers. Further, most of the commercial agriculture in the region is both fuel and electricity intensive and so the continued viability of farming enterprises going forward is uncertain if these cost continue to rise unchecked.

Due to the above, the problem is energy security, and the proposed solution is a new locally cultivated and processed biofuel crop, Solaris. Additionally, the opportunity, especially in the face of the South African Government's biofuel strategy, is that should this crop prove to be viable, there are massive positive implications for social and economic development in a region where many farmers are operating within tight margins, as well as there being ample poverty and unemployment.

Thus, given the suitability of the pedo-climatic conditions for Tobacco in the Loskop farming region, with the idea of replacing a portion of the Classic Tobacco with Solaris, it is of interest to what extent this crop can bring about diesel and electricity independence whilst also contributing to the other environmental, food security, sustainability and development goals of the South African Government.

7.3.Causal Loop Diagram (CLD) Development

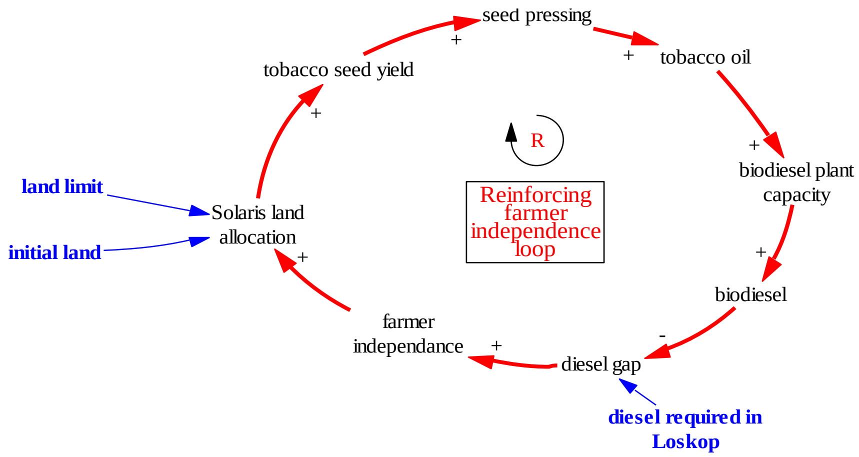

Figure 12: Principle CLD of Solaris adoption in Loskop, displaying fuel independence loop

As a starting point of modelling the implementation of Solaris in Loskop, the base, or principle, CLD was developed. Figure 12 was the first positive reinforcing loop created. It relates an increase in land allocation for Solaris with an increase in production of biodiesel, which increases the farmer's (fuel) independence and thus drives a further increase in land allocation for Solaris.

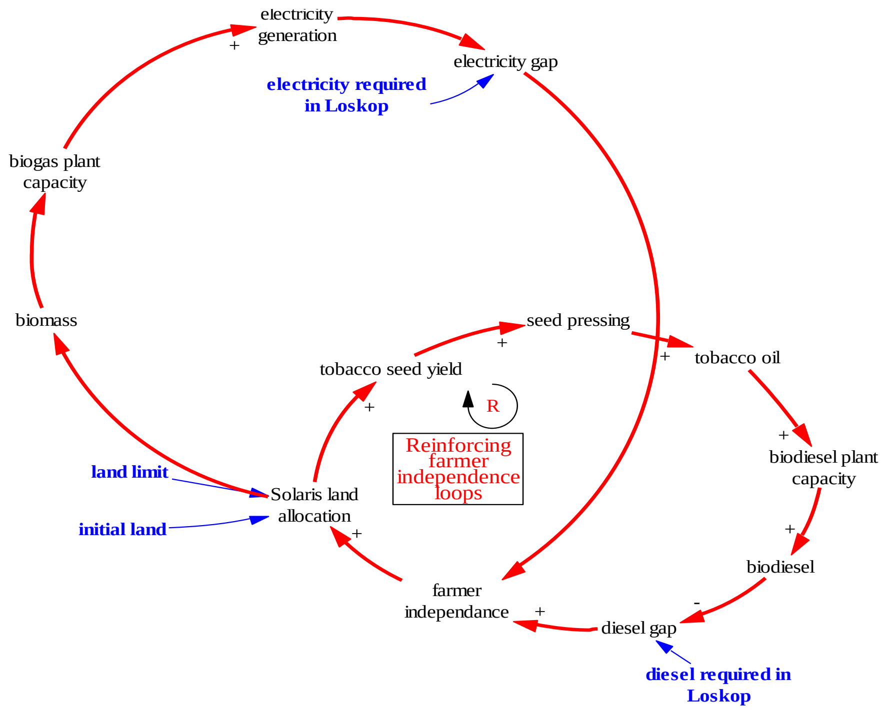

Figure 13: Extended CLD of Solaris adoption in Loskop, displaying full energy independence loops

Given that the importance of energy independence in Loskop is largely related to increasing electricity independence, the CLD was then extended to take into account utilising one harvest of Solaris for biogas, and hence electricity, generation. Figure 13 shows: the more land that is allocated, the larger the biogas potential, and further increase in biogas power plants, and subsequent power generation, serving to further increase farmer energy independence and encourage further land allocation. This is another positive reinforcing loop.

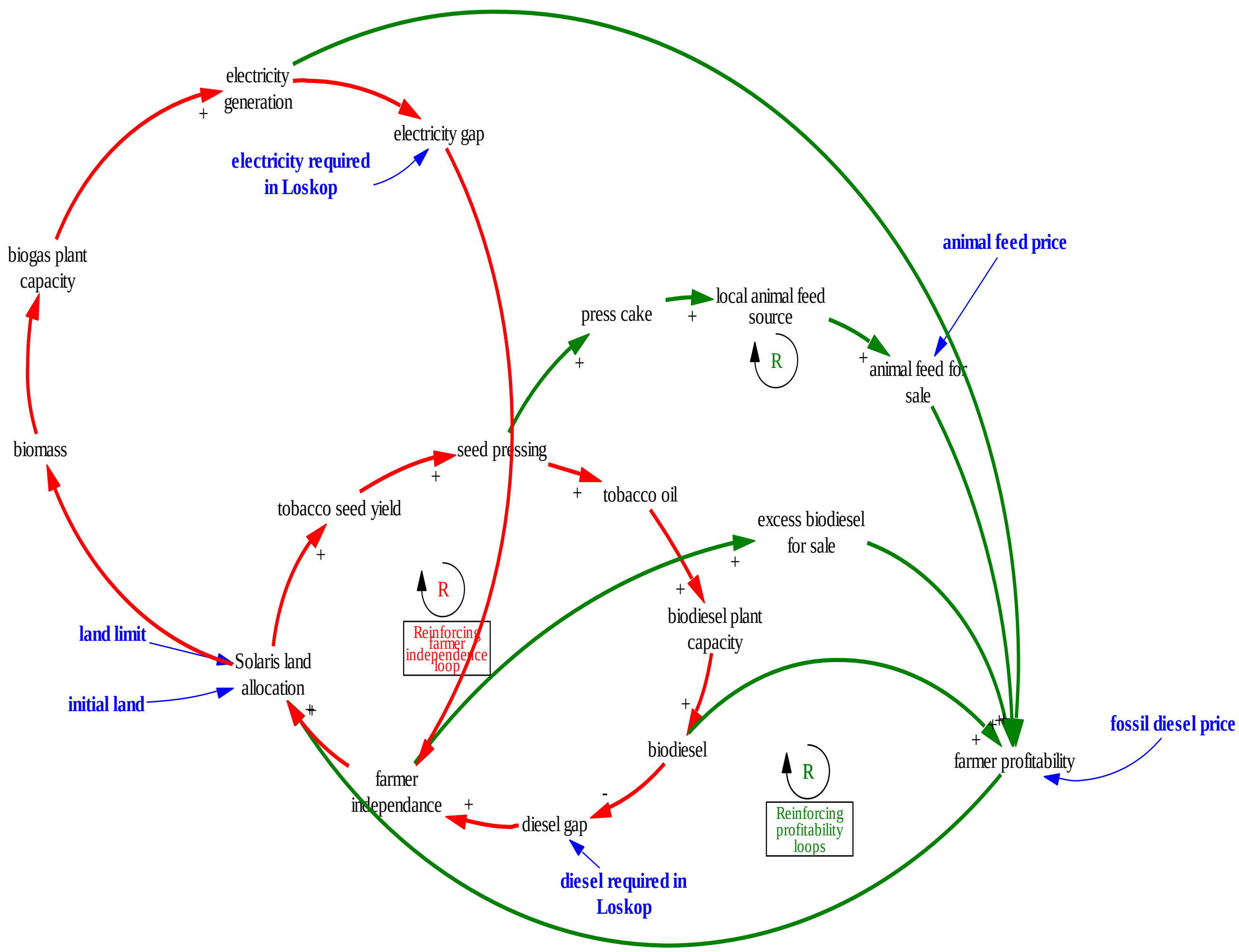

Figure 14: Further extended CLD of Solaris implementation in Loskop, demonstrating electricity and fuel independence loops as well as revenue stream profitability loops

The next driving factor for Solaris land allocation has to do with the profitability of the enterprise, and so the CLD was extended further to take into account all possible revenue streams. If the fuel or electricity produced is being used locally, then the income generated is due to avoided expenses. Further, the emissions avoided by replacing fossil fuel, electricity as well as the post-harvest processes of Classic Tobacco can be considered an income given the Carbon Tax that is mandated for implementation (National Treasury Republic of South Africa, 2012). Seen as further positive reinforcing loops in Figure 14, as revenue streams are increased, then so is farmer profitability increased and hence further increases in land allocation.

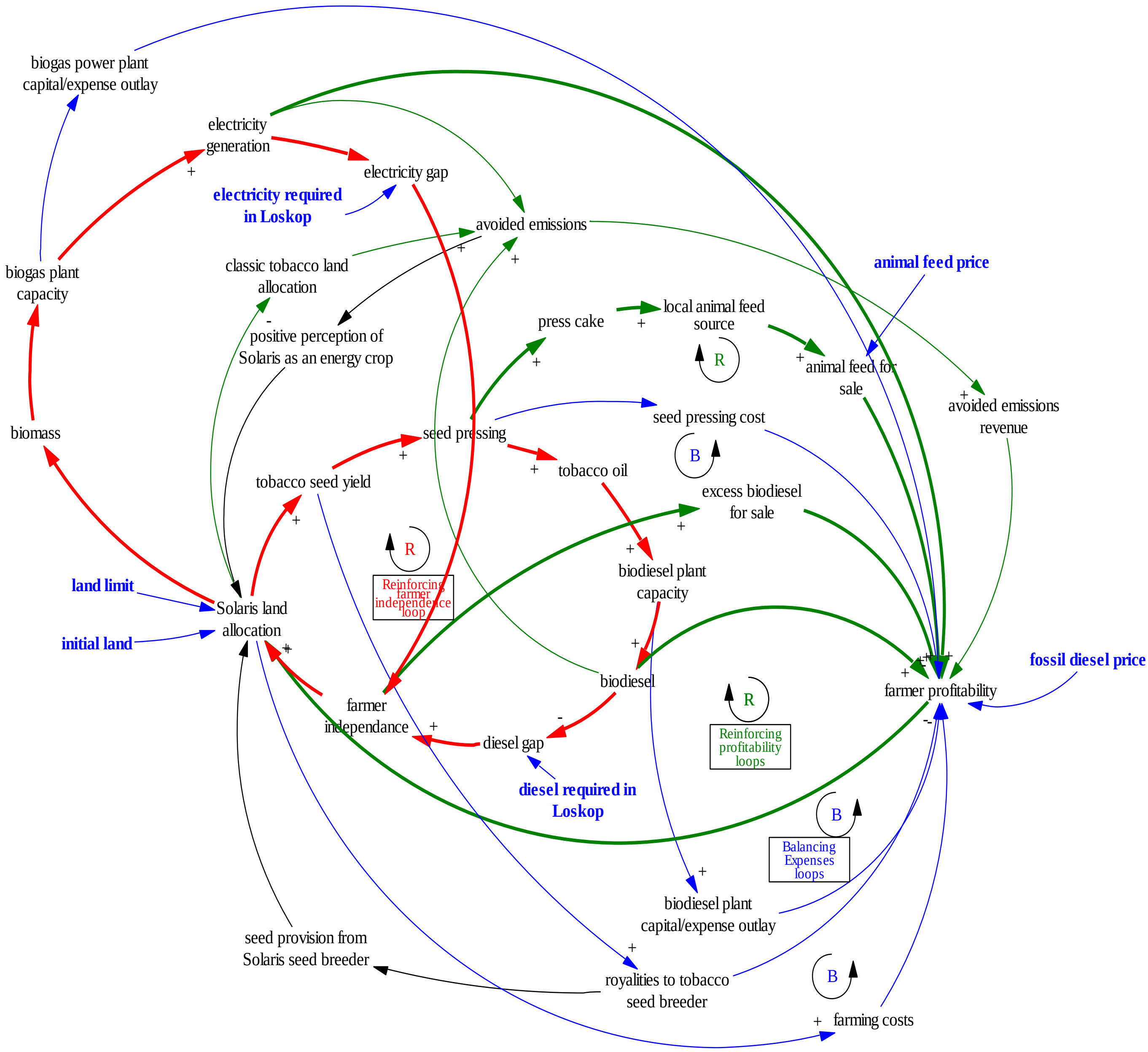

Figure 15: Further extended CLD of Solaris implementation in Loskop, demonstrating positive reinforcing energy independence and profitability loops as well as balancing expenses and capital outlay loops

The farming and processing costs due to the implementation of Solaris were then included to counter the positive reinforcing profitability loops. As shown in Figure 15, balancing loops are introduced for the capital outlays of pressing, biodiesel and biogas power plants, as well as for farming and royalties to the Solaris breeder.

7.4. Stocks and flows and auxiliary variables

Elements of a System Dynamics model can be defined as endogenous, exogenous and excluded. Endogenous elements are those that are governed by internal relationships in the system. Stocks, flows and auxiliary variables are endogenous. Exogenous elements are those that are not affected by the system and are explicitly defined. Excluded variables are merely those which are acknowledged as featuring in the system but are not being included in the specific problem being modelled. For the particular model that was developed for the Loskop Solaris problem using the Vensim System Dynamic Modelling software, the full list of the most important variables and parameters used are described in Table 21 in Appendix D. Table 5 below displays an extract from the full table to provide an example of each element.

Table 5: Example of endogenous, exogenous and excluded variables of the Loskop Solaris System Dynamics Model

Endogenous			**Exogenous**	**Excluded**
Stocks	***Flows***	***Auxiliary***	***Parameters***	
Solaris land allocation	-Solaris new planting rate	-Allocation of Classic Tobacco land to Solaris -Avoided CO2 emissions due to allocation from Classic to Solaris -Effect of energy independence on Solaris planting rate -Effect of energy profitability on Solaris planting rate -Sway of the energy independence driven farmers -Sway of the energy profitability farmers	-Initial Classic Tobacco land (max available to Solaris)	-Effect of Classic Tobacco market

7.5. Key Assumptions, input data and base-run for Loskop Solaris System Dynamics model

Various relationships and parameters were defined in the Loskop Solaris System Dynamics Model programmed into Vensim. This section will define the key relationships, assumptions and real world data used to justify them. The information is based on experience from trials conducted in the area and stakeholder interviews. Data relating to capital outlays, costs, incomes and assumptions about various price escalations were obtained from nationally available sources and relevant companies.

7.5.1. Solaris Planting

As stated in section 7.2, the model is structured such that the only land available for planting with Solaris is that currently utilised for Classic Tobacco. From Table 4, the total available land is 3 673 hectares. Further, it is assumed that once land has been allocated to Solaris it will not revert back to Classic Tobacco land.

Based on time spent with the Loskop commercial farmers, it has been understood that the main drivers for land allocation, particularly for an energy crop, are to do with farmer *energy independence* and farmer *energy profitability*. These concepts have different driving factors but are closely connected to each other. For example, energy independence, which removes reliance on the outside sources, directly relates to profitability as replacing fuel with biodiesel either makes money or loses it depending on yields, how cheaply it can be made and the current diesel price.

The model’s stocks and flows primarily relate the allocation of Classic Tobacco land to Solaris Energy Tobacco land as driven by the various costs and incomes associated with production, infrastructure, usage, sales and emissions avoidance. The types of crops grown in the area, and hence their relative short and long term profitability, govern the influence that energy independence and energy profitability have on the decision to allocate further land. Various parameters relating to the performance of Solaris (e.g. number of harvests, seed yield, etc) directly affect the expenses and incomes and hence the farmer behaviour.

Given that many farmers grow a variety of crop types as well as share co-operatives for storage and processing, there is a certain amount of collective influence. However, it will be swayed in one or another direction by certain factors. As mentioned, driving factors of Solaris land allocation are primarily to do with energy independence and energy profitability. Based on the interviews with local farmers in the Loskop Valley, a relationship between energy independence and energy profitability with planting rate was determined and incorporated into the Vensim model. Figure 16 andFigure 17 below demonstrate these effects respectively.

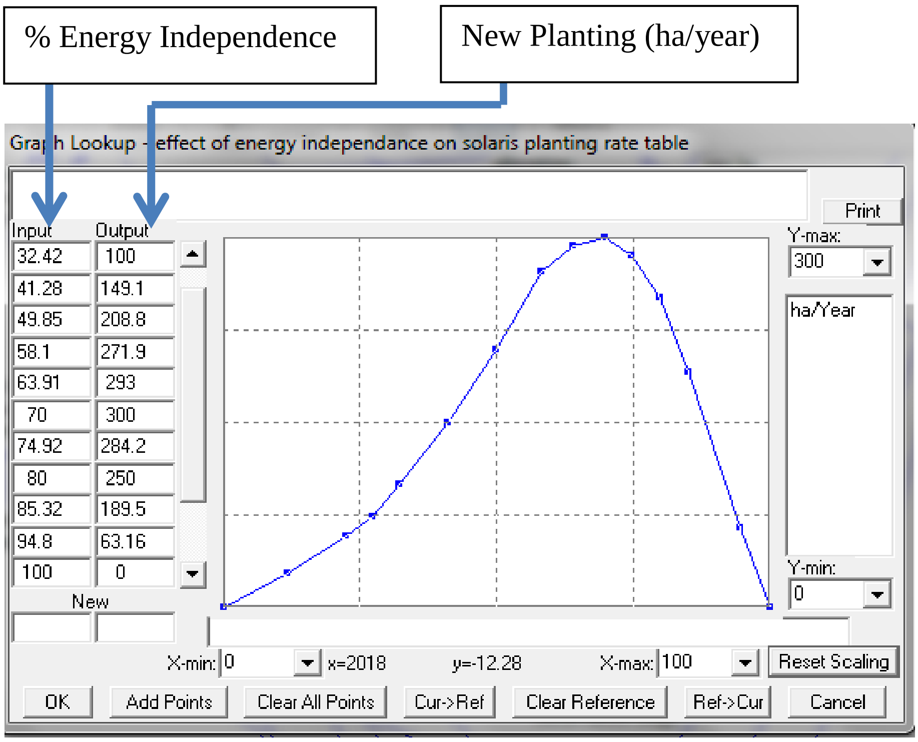

Figure 16: Lookup table in Vensim created to demonstrate the effect the percentage of energy independence has on planting rate

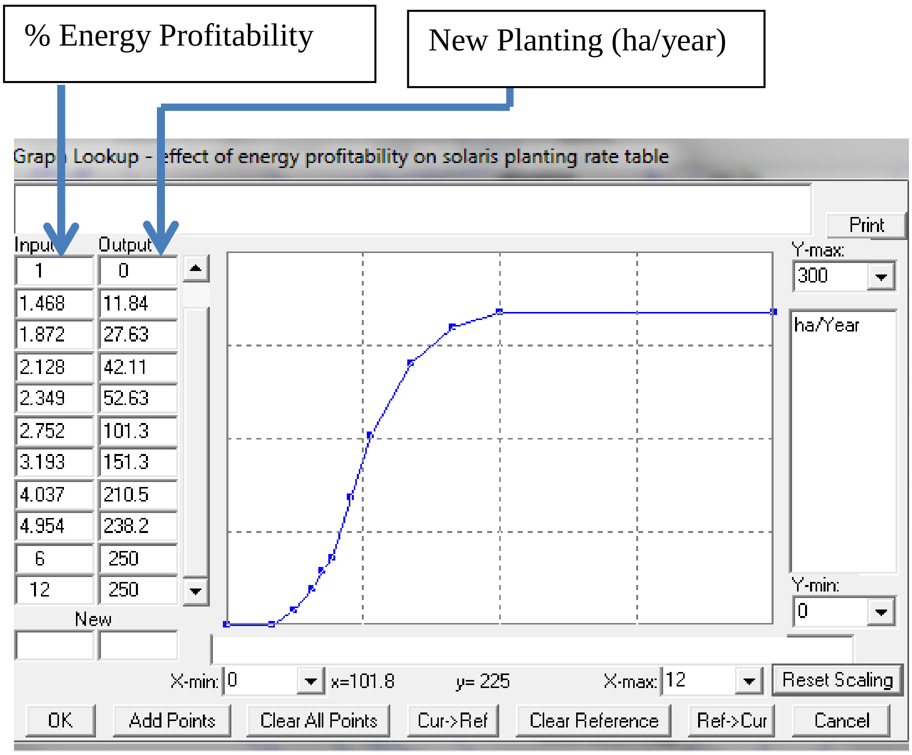

Figure 17: Lookup table in Vensim created to demonstrate the effect that energy profitability has on planting rate

Energy independence was worked out by comparing the fuel and electricity produced by Solaris in relation to the fuel and electricity required by the cultivation activities of Loskop. It's calculated as a percentage and worked out as follows:

$$Energy\ Independence = \frac{Energy\ produced}{Energy\ required}$$

Energy profitability was worked out by dividing the income derived from fuel and electricity production of Solaris with all of the combined expenses of the cultivation and processing activities. Therefore, any value larger than 1 means breaking even in terms of incomes and expenses, i.e:

$$Energy\ Profitability = \frac{Energy\ Income}{Energy\ Expenses}$$

In the case of energy independence, new planting rate is seen to increase exponentially until full independence is reached, after which point the new planting rate drops off. However, as energy profitability increases, the new planting rate also increases quite sharply, but eventually levels out, as there would be a practical limit to the new planting achievable each year.

The dominance of the effect of energy independence on the new Solaris planting rate in comparison to the effect of energy profitability on planting rate is dependent on two factors. The sway of the energy independence driven farmers versus the energy profit driven farmers is determined in relation to their percentage land ownership as well as their financial freedom to invest in initiatives with extended payback periods The permanent crop farmers are the ones whom value energy independence over energy profitability and hence their sway of the planting rate will be governed partially by the percentage of land allocation for their crops in the area at displaying in Table 6 below.

Table 6: Break down of the percentage of permanent versus non-permanent crops cultivated in the Loskop Valley farming community (courtesy of the Loskop Irrigation Board)

	Hectares	Percentage of total
Permanent crops	4800	15.2%
Non-permanent crops	26800	84.8%

However, since the farmers who are motivated by energy independence deal with much larger turnovers and have more capital to spend, they are content with a payback period of 5-10 years. Thus, their influence over driving the increased planting of Solaris, and subsequent processing capital purchases, is much higher than that of the farmers who are short-term profit driven. Therefore according to the model, while the permanent crop farmers have a land allocation of 15.2%, their relative sway over decision making of new planting commands a 35% influence and is based on current and perceived future energy independence they will be able to achieve.

7.5.2. Yields and processing of Solaris

From the preliminary local trials conducted, as described in section 6.7 above, seed yield per plant can be assumed to range between 50-100g of seed per plant per harvest. Plant densities per hectare will range between 40 000 and 60 000. Biomass yields can expect to reach 1-1.5kg per plant.

In terms of oil and press cake yield following the seed being pressed, it is assumed per ton of seed, 300 litres of oil will be obtained and 600kg of press cake. The rest will be assumed to be lost.

In terms of other biomass availability in the area, it has been discovered that that 20-25% of the land in the Loskop region is cultivated with rotation crops for soil improvement each year (Kok, 2013). It is assumed that the Solaris biomass will be matched in quantity due to the resulting biomass of these rotation crops and this will be a contributing source for biogas power generation.

7.5.3. Energy incomes, expenses and cost escalation

Determining fuel and electricity savings as a result of implementing local production due to the introduction of Solaris in the region is calculated based on a variety of factors. Firstly all costs, such as processing costs, equipment costs and farming costs are assumed to escalate over the time period of the System Dynamic simulation. Additionally electricity will also increase in relation to Eskom's proposed tariff increases. Based on data acquired from the Eskom website, an idea of what the average increases in electricity prices has been as well as inflation over a period from 1997-2011 (Eskom, 2013). See Table 23 in Appendix E for details. Thus, in the Solaris Vensim model it is conservatively assumed that the Eskom Tariff will increase by 8% each year and that CPI going forward will be 6% per year.

In terms of Eskom's rural seasonal pricing variations, Figure 62 in Appendix E shows how the current tariffs change depending on the time of year (Eskom, 2013). Using Vensim's Modulo function, Figure 18 below shows the combined effect of yearly price increases and seasonal tariff effects that was input into the model to account for fluctuations over the simulation time period of 20 years. Year 0 in the Figure corresponds to the present year, i.e. 2013.

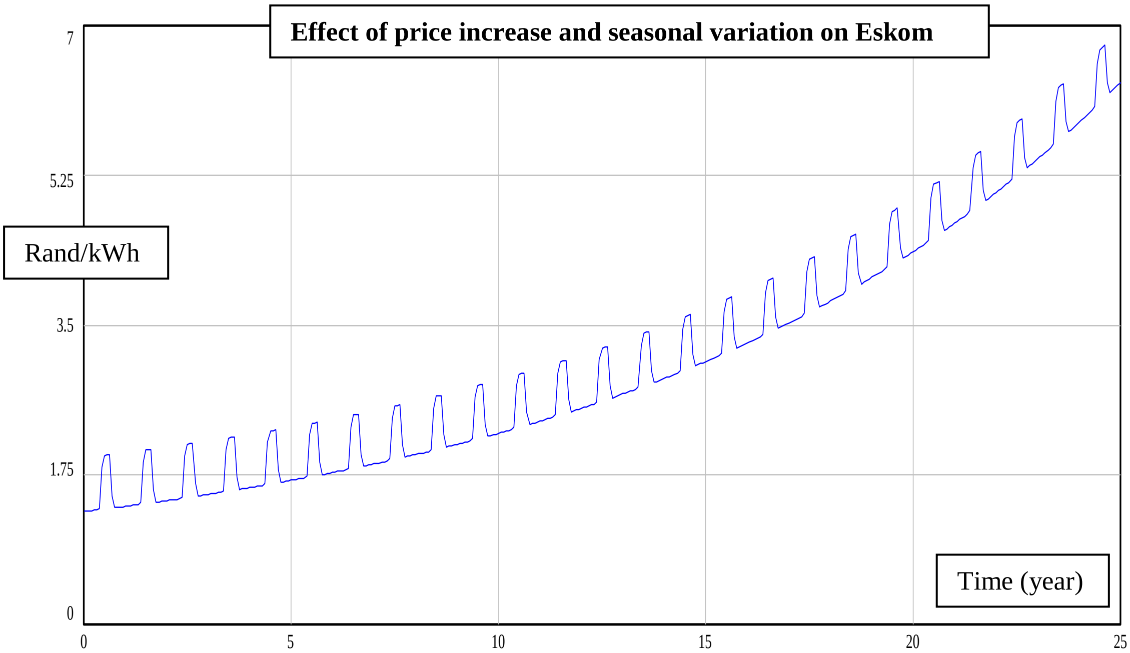

Figure 18: The combined effect of Eskom yearly and rual seasonal price adjustments

However, it should be noted that this assumed Eskom pricing going forward is very conservative as it was not possible to include that the farming enterprises, given their rural locations, pay quite a hefty 'distribution network access charge' based on their line size and distance to substation. It was not possible to estimate this charge per hectare of land farmed, thus, there are in fact significantly more power savings to be made than will be reflected in the results of the simulations.

The final factor to be taken into account with regards to the Loskop Valley electricity consumption and cost is to do with the main driving factor for desiring energy independence in the region. The cold room storage for both citrus and grape is an electricity intensive endeavour that has its peak usage around mid-winter for citrus and mid-summer for grapes in line with their respective harvest periods. Recent Eskom billing was scrutinised for both cold storage instances and the Vensim model was designed to take these energy requirements into account. Figure

19 shows the four month period over the winter season of the year where the electricity effectively increases by a factor of 5 following the citrus harvest.

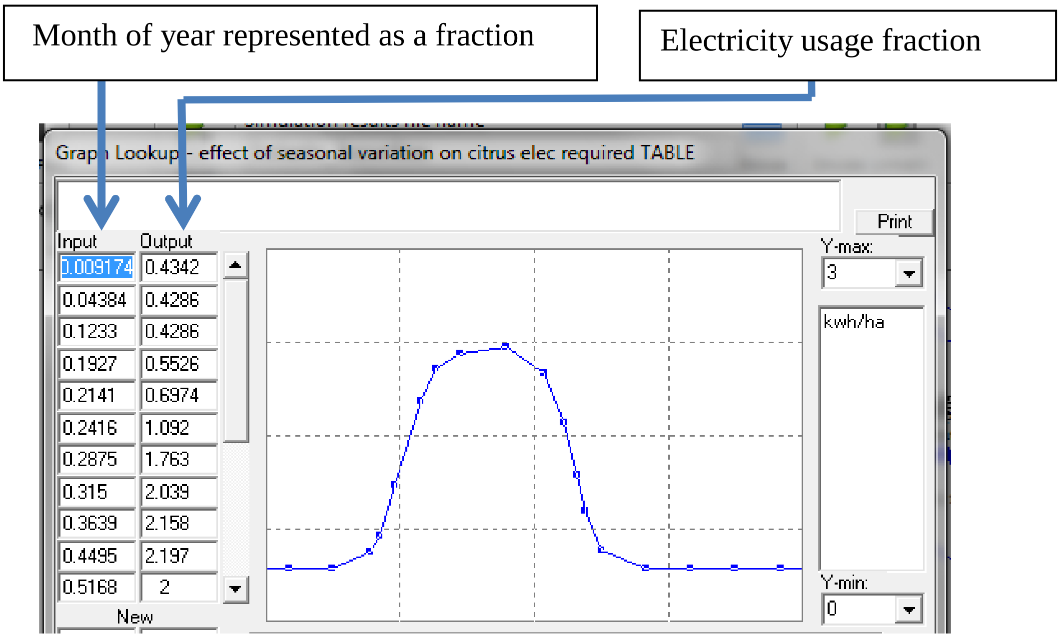

Figure 19: Vensim input table describing the seasonal variation of electricity required for citrus

Figure 20 shows the three month period in the year over the summer season where the electricity effectively increases by a factor of 5 following the grape harvest.

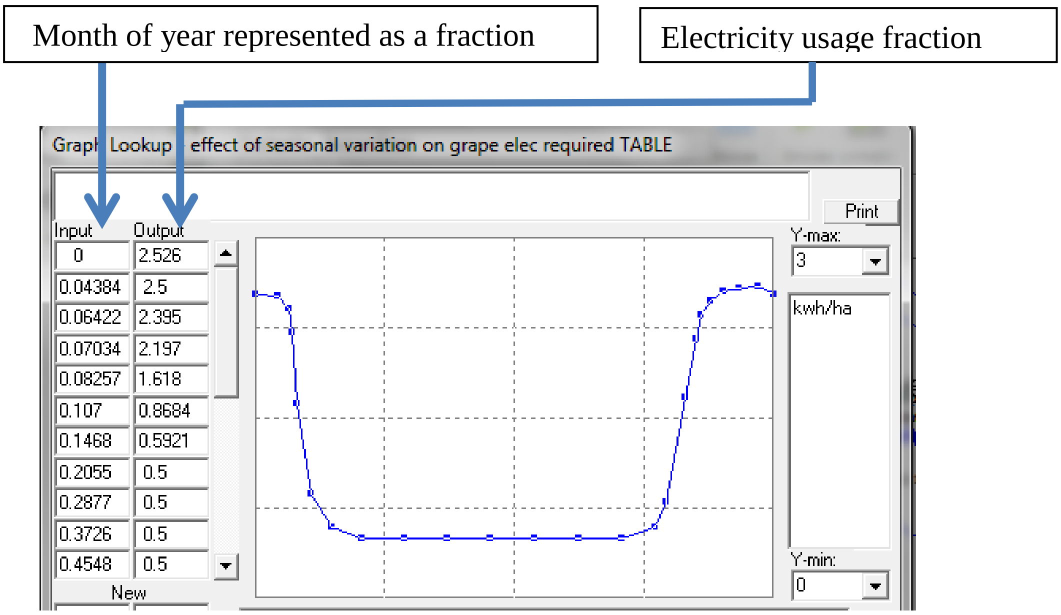

Figure 20: Vensim input table describing the seasonal variation of electricity requirement for grapes

The South African diesel price trend from the period of 2002-2013 was used to define a projected diesel price for the 20 year simulation period. Figure 21 displays the pricing trend over those years and assumed pricing gradient going forward. The

Vensim simulation will begin assuming a petroleum diesel price of R12 per litre and following a linear progression will arrive at R38 per litre after 20 years.

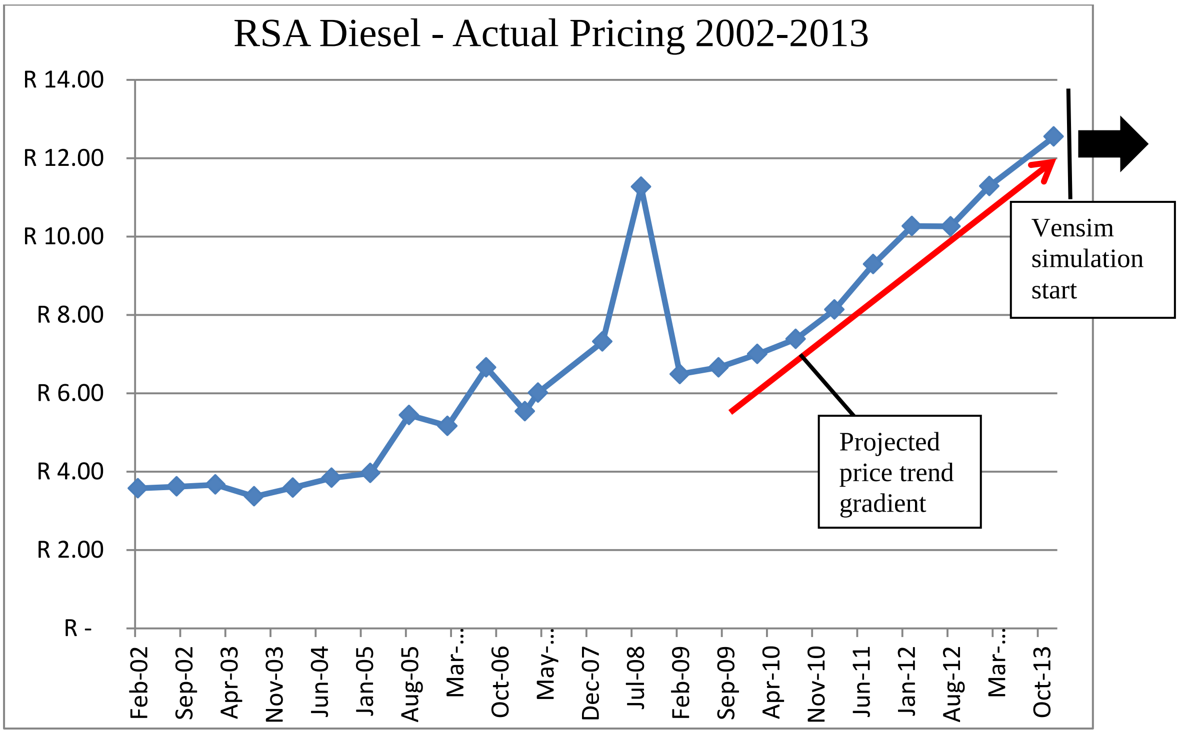

Figure 21: South African Diesel and Petrol price from 2002-2013 taken from (Automobile Association RSA, 2013) and (Engen, 2013)

7.5.4. Emissions Avoidance Assumptions

In terms of emissions considerations there various ways that the Solaris cultivation has been determined to be able to impact upon climate change. All the assumptions about emissions avoidance are based on the premise that in this particular system Solaris land allocation will only be as a result of replacing Classic Tobacco cultivation land. Further, the substituted Classic Tobacco cultivation is then assumed to not replace cultivation elsewhere. As such, any emissions that could result from direct or indirect land-use change, as mentioned in sections 5.2.1 and 5.2.2, are assumed to be excluded.

Classic Tobacco and Solaris undergo the same cultivation procedure up until harvest, so it is assumed that any carbon dioxide (CO_2) emissions as a result of cultivation (i.e. working the land, fertilisers and so on) are identical up until that point.

Following harvest, Classic Tobacco leaves require large quantities of coal for curing purposes. Due to this, the first avenue of avoided emissions resulting from the adoption of Solaris is avoided coal emissions. Interviewing Classic Tobacco farmers in the Loskop region has revealed that 4 tons of coal is used for the curing of one hectare of Classic Tobacco harvest (Kok, 2013). Utilising data from the USA

Energy Information Agency it was determined that 1 ton of coal translates to 2.9 tons of CO_2 (B.D. Hong, 1994). Thus, per year each hectare of Solaris results 11.7 tons of avoided CO_2 emissions from the burning of coal. See Appendix B for calculations.

The second avenue of emissions avoidance of Solaris biodiesel is as per typical values associated with the production and combustion of biodiesel in place of petroleum-based diesel. 3.6 kg of CO_2 are avoided per litre of Solaris biodiesel utilised (A.L Stephenson, 2010). See Appendix B for calculations used.

The third and final avenue of emissions avoidance utilised in this model is related to biogas electricity generation. Calculated as per the accepted methodology of the United Nation Framework Convention on Climate Change (UNFCCC), the CO_2 emissions per Megawatt hour (MWh) of electricity generated from the predominately coal powered Eskom grid in South Africa, results in approximately 1 ton CO_2/MWh (I. Goryashin, 2012). Therefore, in the Vensim model, it is assumed that every MWh produced by biogas power generation results in the avoidance of that quantity of emissions. Any other emissions due to the biogas power plant are assumed to be negligible.

The monetary value attached to these avoided emissions is based on the proposed South African Carbon Tax policy. As per the Budget Review of 2012 the assumed value per avoided ton of CO_2 is R120 (National Treasury Republic of South Africa, 2012).

7.5.5. Capital outlay and other revenue assumptions

Capital outlay and revenue assumptions, shown in Table 7, used in the Vensim model were based on various quotations from industry. The simulation begins with one seed press and one biodiesel plant being purchased. As land allocation increases and with it seed yield, additional units and associated capital expenditure is made. The first capital outlay for a biogas power plant only occurs once the model is producing 80% of the biomass required to function at full capacity. Once again further biogas power plant units are only included as further land allocation allows.

It is acknowledged that should this project behave as desired, a bankable feasibility study could be developed fairly soon in relation to this simulation time span. This could allow for significant project financing and far larger investments in processing equipment which could take advantage of economies of scale. For the purposes of this model however, the acquisition of capital occurs in an organic fashion, growing modularly, only as the system allows.

Table 7: Industry quotations for pressing, biodiesel and biogas plant outlay, as well press cake revenue

Product	Outlay/ Revenue	Size	Company	Price per unit
Seed press	Outlay	500kg/hour	Flora Power - Germany	R700 000
Biodiesel plant	Outlay	4000 litres/day	Green Diesel - CPT	R250 000
Biogas Plant	Outlay	250 KW	Host - Holland	R32 000 000
Press Cake	Revenue	1 ton	Grains for Africa- JHB	R3 500

7.5.6. Base run of Loskop Solaris System Dynamics model

Given that there were a variety of model and simulation adaptations following the System Dynamics workshop, which will be discussed in Chapter 8, only the results of the baseline run of the System Dynamics model, defined in Table 8, will be shown for illustration. The time frame for simulation is 20 years, where year 0 is assumed to be 2013.

Table 8: Key features of the initial Baseline run of the Loskop Solaris System Dynamics model

Scenario	Initial land allocation	Seed yield per plant	Biogas power	Number of seed harvests
Baseline	100 Ha	50g/harvest	Yes	3

As per Figure 22 the land allocation is sluggish to start and picks up towards the end of the period, as corroborated by the yearly planting rate shown in Figure 23.

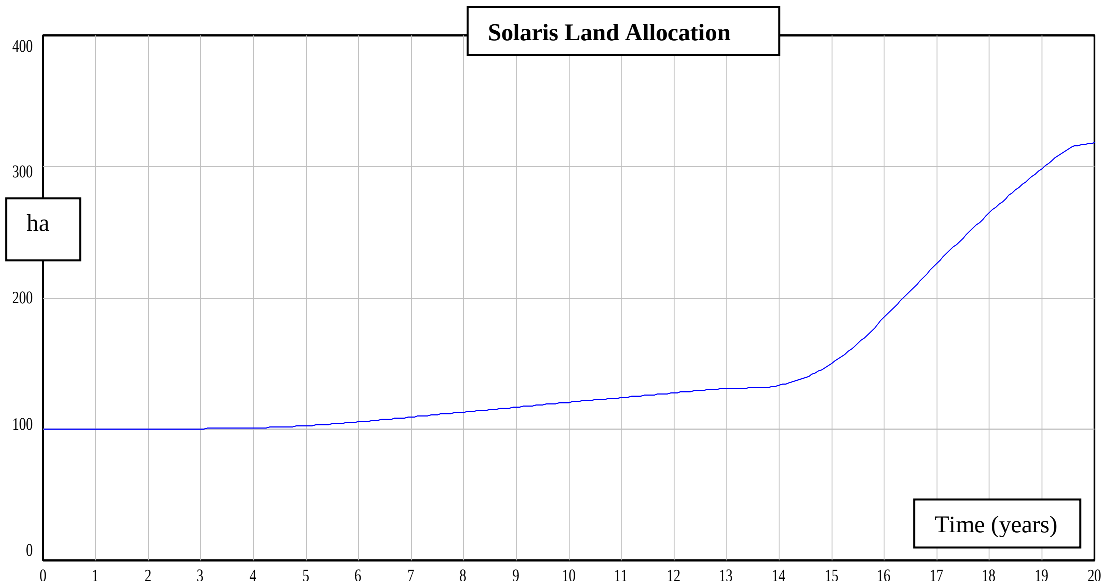

Figure 22: Inital baseline run of Loskop Solaris model showing the Solaris land allocation

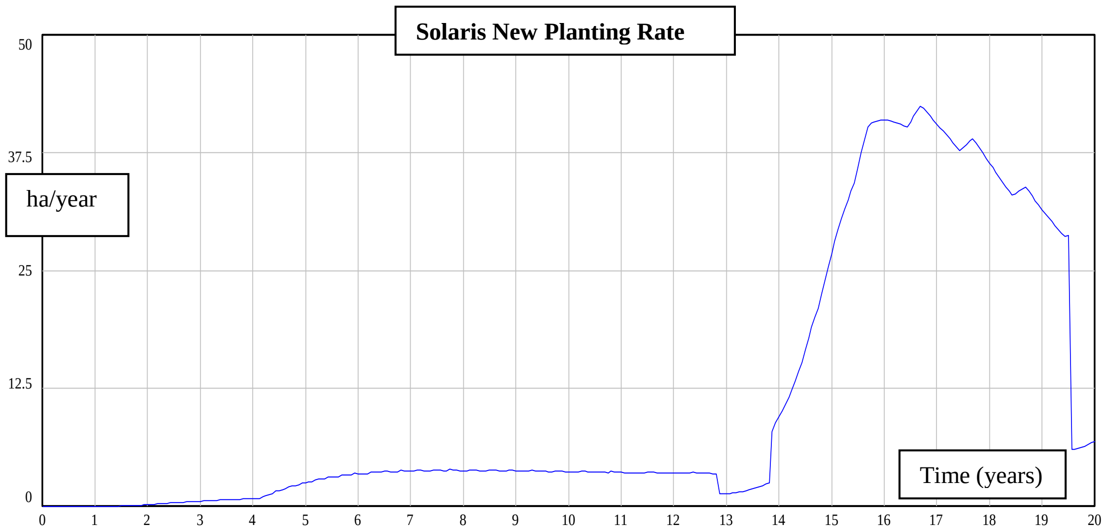

Figure 23: Initial baseline run of Loskop Solaris model showing the Solaris new planting

The graphs below demonstrate the causal links between energy independence and profitability to increasing Solaris land allocation. Figure 24 demonstrates the relationship between increased fuel and electricity independence and the change in land allocation. Figure 25 shows how the Solaris new planting rate is a combination of the effect of energy independence and energy profitability based on the Solaris cultivation already occurring.

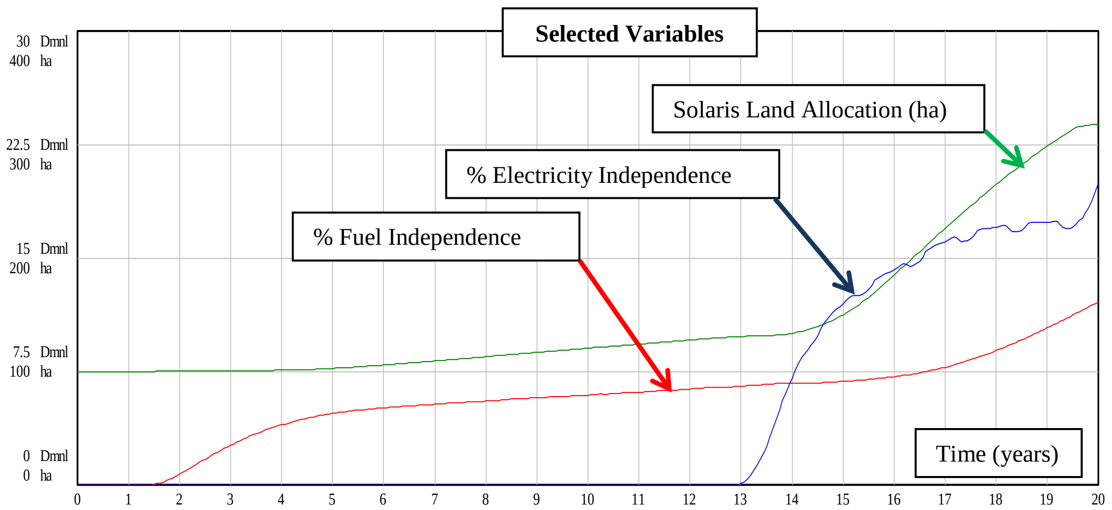

Figure 24: Preliminary baseline run of Loskop Solaris Vensim model showing the Solaris land allocation as related to electricity and fuel independence

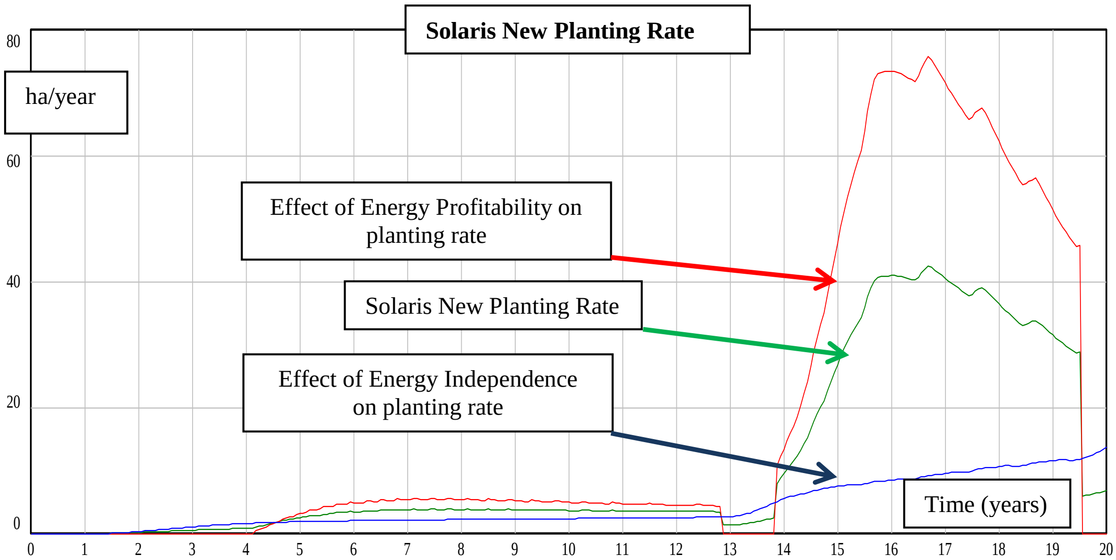

Figure 25: Initial baseline run of Loskop Solaris model showing how Solaris new planting swayed by energy independence and profitability

This version of model was designed to include full and immediate payment of any capital outlays required for biodiesel and biogas processing plants required. As such, Figure 26 and Figure 27 display sharp changes at those junctures to the expenses and profitability respectively.

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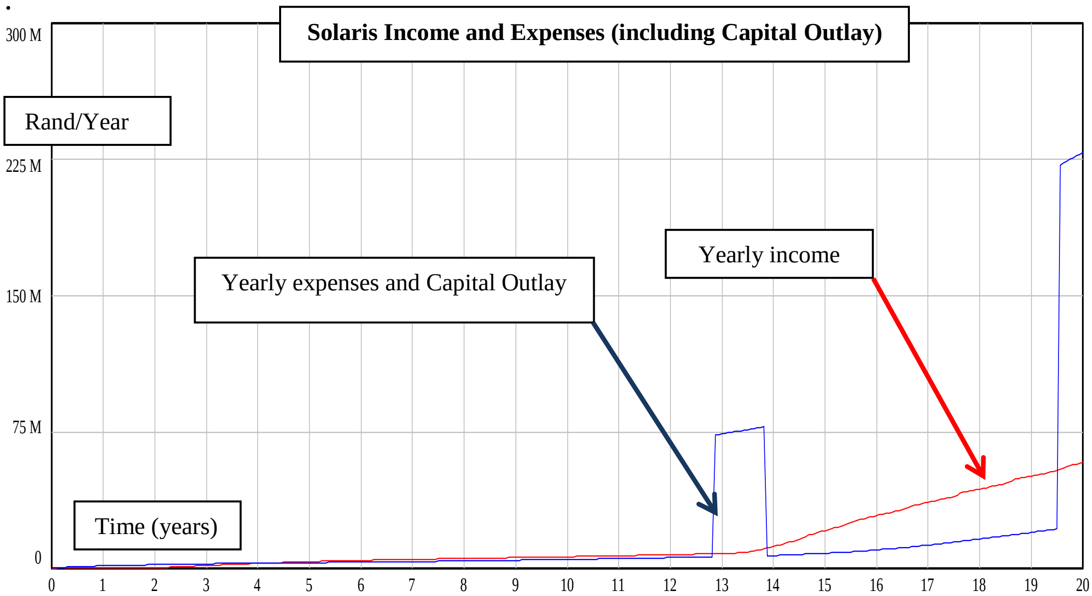

Figure 26: Initial baseline run of Loskop Solaris model showing how the income generated due to the cultivation and processing is related to the combination of expenses and capital outlay.

As previously stated, according to this model, profitability is determined as being income divided by all expenses (including capital outlay at this stage) and thus anything less than 1 is a situation where costs are not being covered. Figure 27 demonstrates the profitability over the simulation period. As mentioned, the profitability is seen to take a dip whenever substantial new capital purchases are required and thus this effect is carried through to the new planting rate in Figure 23.

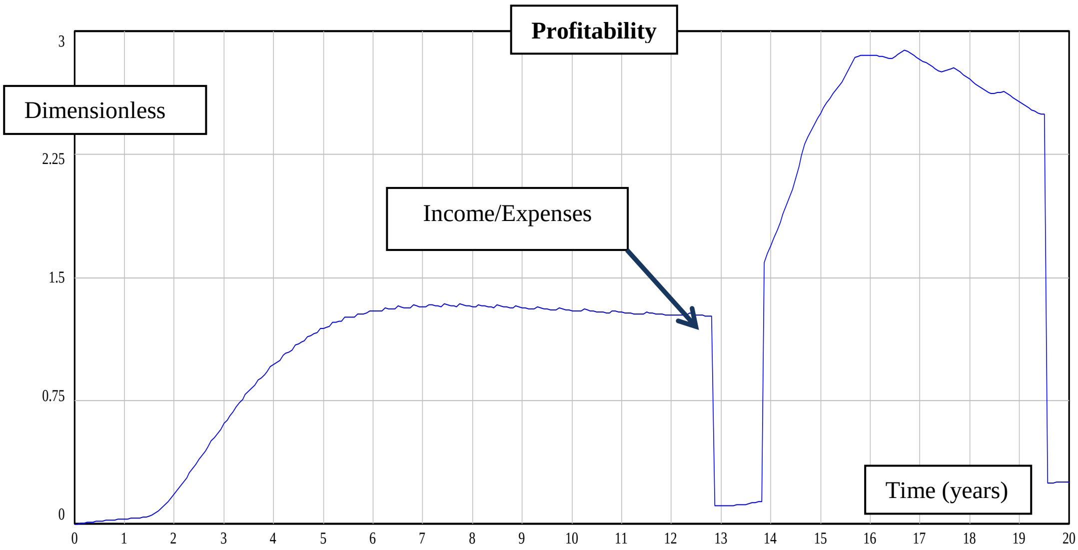

Figure 27: Initial baseline run of Loskop Solaris model showing the profitability of the system

8. Mini System Dynamics workshop

Another Systems Thinking tool was utilised in the further development of this study. Following a few iterations of model development, a Systems Dynamic workshop was held at the University of Stellenbosch with key stakeholders. By engaging experts in the field, this was done to critique the structure of the model and the outcomes it is striving to obtain. Members of academic staff from Stellenbosch University as well as the CSIR who had backgrounds in renewable energy, biofuels, Systems Thinking and System Dynamic Modelling attended as well as other individuals involved in the actual running of the trials in Loskop. See Table 9 below for the workshop attendees and their designations. The background of the project, as described in the first few chapters of this report, as well as the most current Vensim model and results at that time was presented. What follows in this chapter is a brief discussion of the relevant issues that were raised in the workshop, the advice given in terms of model reworking and well as the changes which would be implemented subsequent to the workshop.

Table 9: Attendees of the Systems Thinking workshop held with regard to the Loskop Solaris System Dynamics modelling process on 30/10/2013

Attendee	Affiliation	Field
Dr L de Lange	Gaia Carbon Sciences	Systems Thinking
Prof JL van Niekerk	Stellenbosch CRSES	Renewable Energy
Dr W Stratford	Stellenbosch CSIR	Systems Thinking
Dr G Forsyth	Stellenbosch CSIR	Systems Thinking
Dr J Musango	Stellenbosch Sustainability Institute	Systems Thinking
Prof A Brent	Stellenbosch CRSES	Renewable Energy & Systems Thinking
Mr J van Lier	Toboil (Pty) Ltd	Renewable Energy
Mr D Masureik	New Southern Energy (Pty) Ltd	Renewable Energy
Dr T de Wet	Gaia Carbon Sciences	Systems Thinking
Ms K Kritzinger	Stellenbosch CRSES	Renewable Energy

8.1. Discussions points about Solaris Loskop system dynamic model

Following the presentation, the discussion topics among the attendees fell into three distinct categories. These categories were to do with environmental issues, economic or financial matters as well as the social effects of the system. The discussions were quite extensive and given that a fair amount of them were to do with clarifying project details only discussion points relating to challenging model the structure and its interconnections will be detailed.

Based on the discussion topics, certain assumptions were defended, and thus not changed. Certain items were not possible to change due to time constraints and will be considered in future work. Lastly, certain items resulted in model restructuring. All of the relevant discussion topics and how they were addressed will now be described.

8.1.1. Environmental issues

No	Question/concern raised	Question/concern addressed
1	Have the net energy and emissions in the system been calculated for the full life cycle of all the cultivation and product processing?	Given that the land allocation for Solaris in this particular model is only coming from land currently allocated to Classic Tobacco, and with the assumption of no land-use change as a result, it is assumed that emission effects of section 7.5.4 are sufficient as they are. Future work will consider the additional energy required in the pressing and biogas process however for the current model they will be overlooked
2	Do increases in seed yield mean increases in fertiliser and hence an increase in costs and emissions?	Given that this is a new crop in the area and considering results from trials elsewhere in the world, increases in yield are assumed to largely be a result of optimising the cultivation process and not due to additional fertiliser usage. In this way additional yields will not result in additional energy use and emissions.
3	What are the processing assumptions of the biogas plant? I.e. the Solaris biomass is not the only input into the system (other manure, plant matter, water, etc required)	It is assumed that any additional input requirements to the biogas plant (such as manure, other plant matter, water, etc) will be met by the community based on the crops and animals reared in the area and that the water component is not large enough to be considered (although will be considered in future work).
4	Is biogas power generation the best use of the biomass	This is also a matter that will be researched in future work, along with considering integrated

	or is a co-firing plant more viable?	solutions of solar and hydro power. Presently it is assumed that all additional power generation is due to biogas power plants.
5	Have the other by-products of the biogas plant been taken into account? – i.e fertiliser by-product	Whilst it has been acknowledged that there is a fertiliser by-product, which could result in lowering the requirement for purchasing fertiliser for agriculture in the area, it is presently too complex to factor this in and will be considered in future work.
6	Have other biofuel feedstocks been compared in relation to their environmental effect?	The Vensim model will need to be adapted quite significantly to take other feedstocks into account in the system and so will be considered in future work.
7	Is there enough biomass generated at consistent intervals all year round for a biogas plant to be able to run?	Is assumed that excess biogas generated when biomass is plentiful can be stored for when it is required

8.1.2. Financial issues

No	Question/concern raised	Question/concern addressed
1	The profitability is very "spiky" and it is not realistic that the community would pay in full immediately for new processing plants. They would apply for financing which they would pay off over a reasonable period.	The financial side of the Loskop Solaris system dynamic model in Vensim was completely restructured following the workshop. Capital purchases of press equipment, biodiesel plants and biogas plants are included into the model as loans that are paid back incrementally over a 10 year period following their purchase. The remaining loan balance at any point will result in a yearly expense of interest on balance owed using the current prime interest rate value of 8%.
2	Why modular additions of processing units instead of taking advantage of economies of scale?	Given that the idea of this model is to allow Solaris land allocation to be driven by the perceived benefit of energy profitability and energy independence in the community, a modular process of equipment acquisition was required. If very large-scale processing was employed, a hefty start-up land allocation would be required which would tie the community in for a long time. Given that the crop needs to prove itself as well as allow farmers the opportunity to learn about it, which includes learning to transition from

		petroleum diesel and Eksom power, large scale adoption early on is risky and can led to the same pitfalls as was spoken about with regard to Jatropha in Section 5.3. Further, there may be increased opportunity for job creation in this manner of doing things.
3	Can the cost of diesel be worked out in terms of Rand/litre?	The model will be adjusted to determine the cost of biodiesel in terms of Rand/litre.
4	Can the cost of power be worked out in terms of Rand/kWh?	The model will be adjusted to determine the cost of biogas electricity in terms of Rand/KWh.
5	Can a comparison be made in terms of profits farmers can make per hectare with Classic Tobacco and Solaris?	Future work will consider how the Classic Tobacco Market could affect Solaris land allocation.
6	Practically, how many hectares and yield is required to be a viable system? As well as a fully independent system?	Scenarios will be run to determine how many hectares (with associated yields) are required to establish a fully independent and viable system.
7	Have other biofuel feedstocks been compared in relation to their financial viability?	The Vensim model will need to be adapted quite significantly to take other feedstocks into account in the system and so will be considered in future work.

8.1.3. Social issues discussed

No	Question/concern raised	Question/concern addressed
1	This system is not on previously disadvantaged land, therefore how can it be contributing towards rural development?	The greater goals of the 2007 South African Biofuels Strategy to do with rural development are not directly being looked at in this model. However, the need for employment and social upliftment in the Loskop Valley means that any benefits to the marginalised members of the community due to the Solaris implementation and processing will benefit those individuals that the Strategy is aimed at. Further, the lessons learnt here can result in the development of a system that can be implemented in those regions of the country.
2	Since irrigation required, will this crop not face barriers in terms of rural	Further time spent working with the crop in South Africa will mean that it can be understood if there is the potential to grow it in

	development?	certain regions without irrigation. Currently Solaris requires irrigation and so the extent to which it could form part of a rural development solution is called into question. However, it is important to move through the trial phases to understand these issues fully as well as what would be the most sustainable mode to employ it in the previous homeland areas.
3	What is the farmer perception around growing biofuel crops (new or otherwise)?	Time spent in the community has revealed that farmers are fairly resistant to change, both in terms of biofuel crops as well as in terms of new varieties of crops. This is another reason why the modular, farmer-driven approach is being adopted in the model for Solaris land allocation.
4	Is the replacement of Classic Tobacco realistic? Would farmers do it? I.e. taking into account long-standing relationships with suppliers, like British American Tobacco (BAT)	Although farmers to have a long-standing relationship with suppliers, like BAT, they are also faced with other concerns of energy profitability and energy independence. It is thought that whilst a full adoption of Solaris in favour of Classic Tobacco is not likely, a substantial allocation thereof is feasible.
5	What is the effect on employment (skilled and unskilled) due to processing done in community?	The model will be reworked to demonstrate how much employment as well as how much of the finances of the system will be directed towards employment (both skilled and unskilled) due to Solaris cultivation and processing. Table 10 shows the employment figures that will be utilised for the various processes required.
6	Would this crop allow farmers to be in a better position to negotiate with suppliers (like British American Tobacco) due to having other cultivation options?	Due to time-constraints, the effect on the Classic Tobacco market is not considered.

Table 10: Assumed processing employment details for Loskop Solaris Vensim Model

	Skilled Labour	**Unskilled Labour**
Employees required for unit pressing plant	1	1
Employees required for unit biodiesel plant	1	1
Employees required for unit biogas plant	1	1
Initial Yearly Wage	R120 000	R36 000

8.2.Additions to the stocks, flows and auxiliary variables

The adaptations made to the Loskop Solaris System Dynamics model following the workshop resulted in the addition of several stocks, flows and auxiliary variables. The most important of these can be seen in Table 22 in Appendix D

9. Loskop Solaris Vensim Simulation Scenarios and Results

After implementing the changes in the model following the System Dynamics workshop described in Section 8, the final version of the Vensim model was developed. Once again, it was set up to simulate over a 20 year period beginning at 2013. The graphical representation of the model can be seen in Figure 58 and Figure 59 in Appendix A. This chapter will describe the scenarios simulated in Venism as well as a comparison of the results obtained.

9.1.Loskop Solaris Vensim Scenarios

Table 11:Scenarios of the Loskop Solaris System Dynamics model developed in Vensim

Scenario	**Initial land allocation**	**Seed yield per plant**	**Biogas power**	**Seed harvests/season**
Baseline	100 ha	50g/harvest	yes	3
Scenario 1a *(yield comparisons)*	Baseline	30g-100g/harvest	Baseline	Baseline
Scenario 1b *(yield comparisons without biogas power)*	Baseline	30g-100g/harvest	no	Baseline
Scenario 2 *a* *(Land boost)*	500ha	100g/harvest	Baseline	Baseline
Scenario 2 *b* *(Land boost without biogas power)*	500ha	100g/harvest	no	Baseline

9.2.Results

9.2.1. Baseline Results

The Baseline scenario, described in both Table 8 and Table 11, was re-simulated to take into account the modifications following the System Dynamics workshop. A more realistic evolution of the system is evident as indicated by the figures below. Note once again that year 0 is equivalent to the present year 2013.

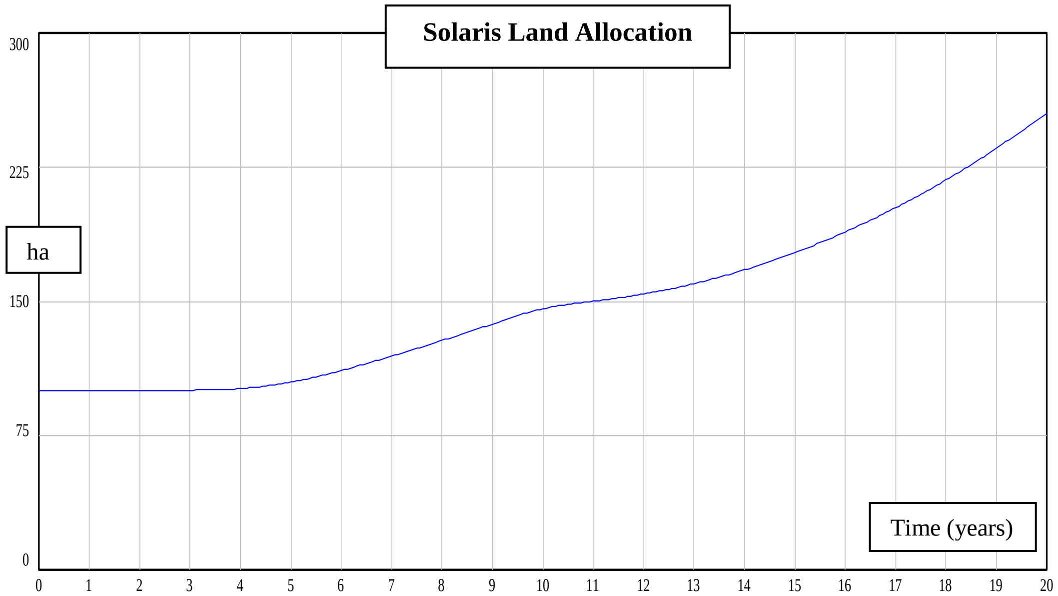

Figure 28: Baseline run - Solaris land allocation

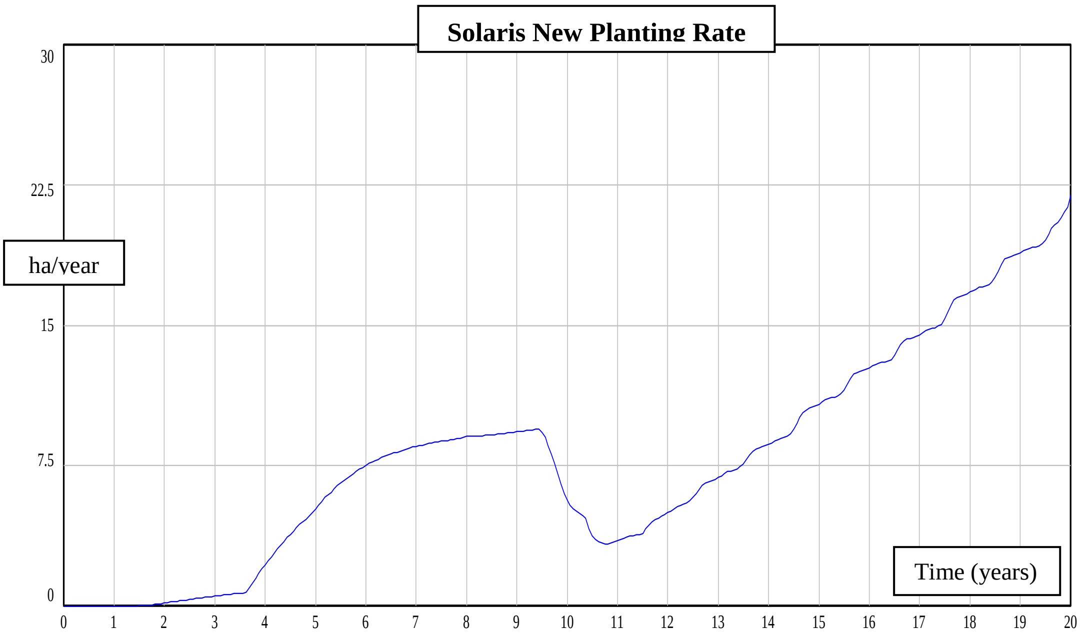

Figure 29: Baseline run - Solaris new planting rate

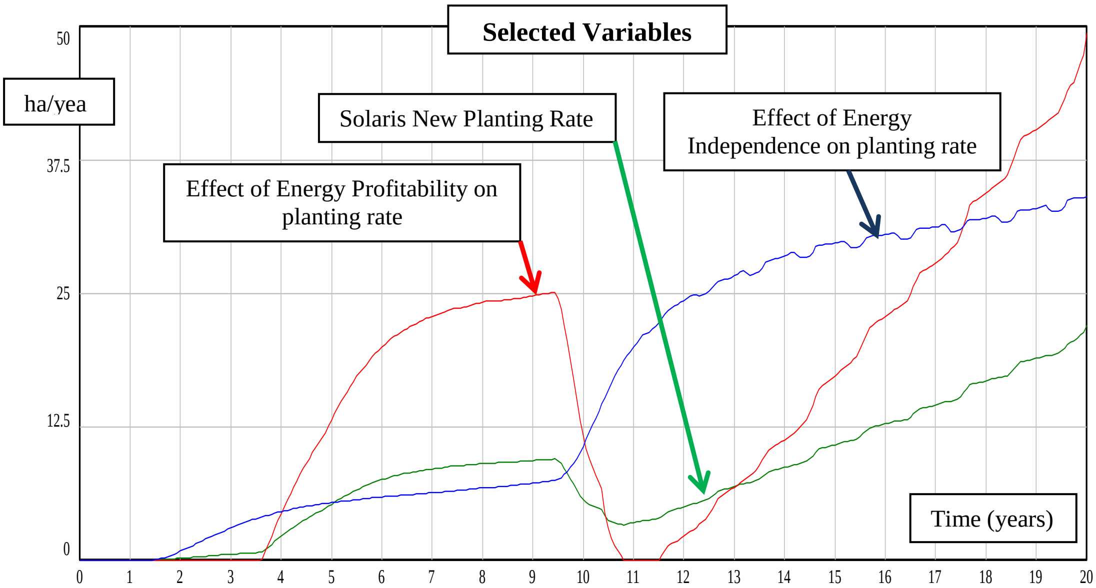

Figure 30: Baseline run – Demonstrating how the Solaris new planting swayed by energy independence and profitability

As displayed in Figure 28, the land allocation begins to rise steadily after year 4. The new Solaris planting rate presented in Figure 29 is less "jumpy" than in the initial baseline run shown in Figure 23. This most likely due to the new manner of loan repayments which more evenly distributes the capital outlay over the simulation period and hence positively affects the profitability of the system. Figure 30 highlights the effect that energy profitability and energy independence has on the new Solaris planting rate.

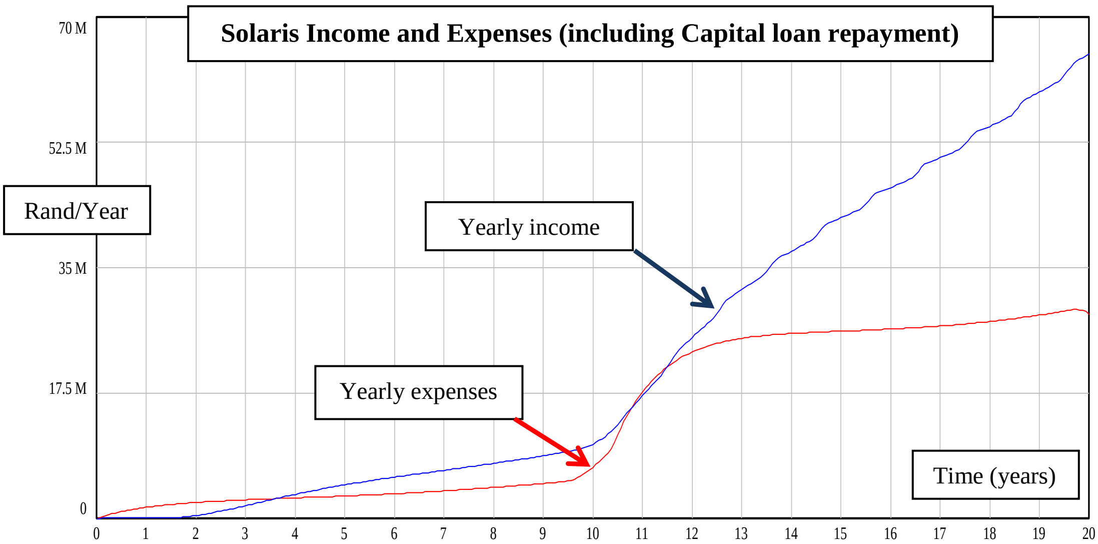

Figure 31: Baseline run –Solaris Income and Expenditure

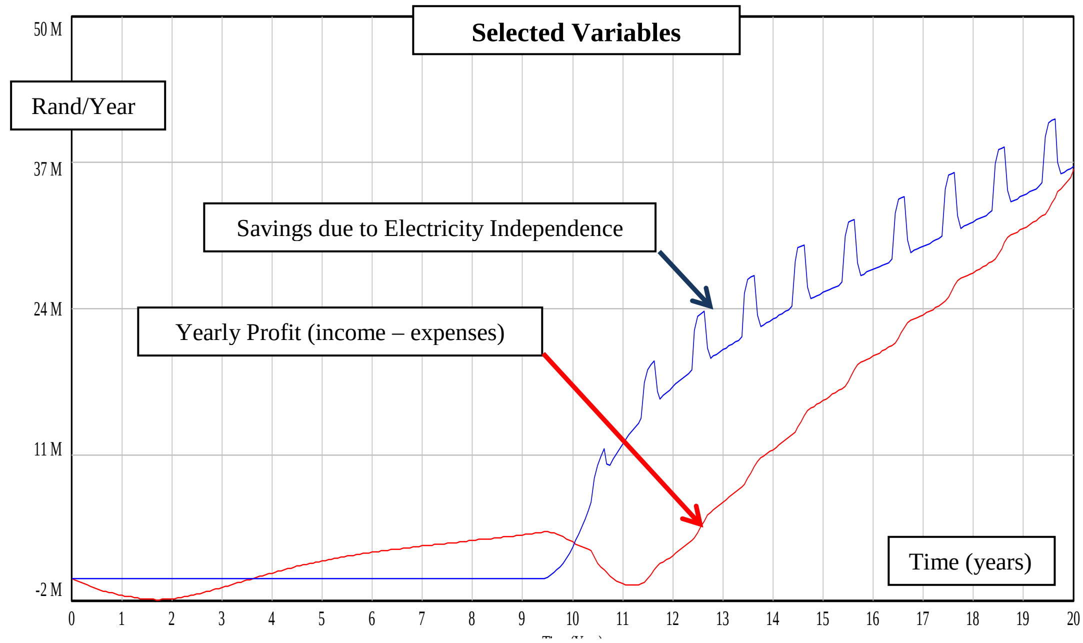

Figure 32: : Final baseline run of Loskop Solaris Vensim model showing value of Solaris biogas power generation in terms of project Eskom tariff

Once again due to the restructuring of the finances, the yearly income and expenses track each other in a smoother fashion in Figure 31 than seen in the initial run in Figure 26. Also from Figure 31, the system income is shown to radically change course following year 11. This coincides with the first capital investment of a biogas power generation plant indicated in Figure 32 by the savings incurred due to electricity independence from Eskom. The yearly profits initially take a dip as the electricity savings are incurred, but this is due to the initial costs and loan repayment of the biogas power plant before it starts running at full capacity.

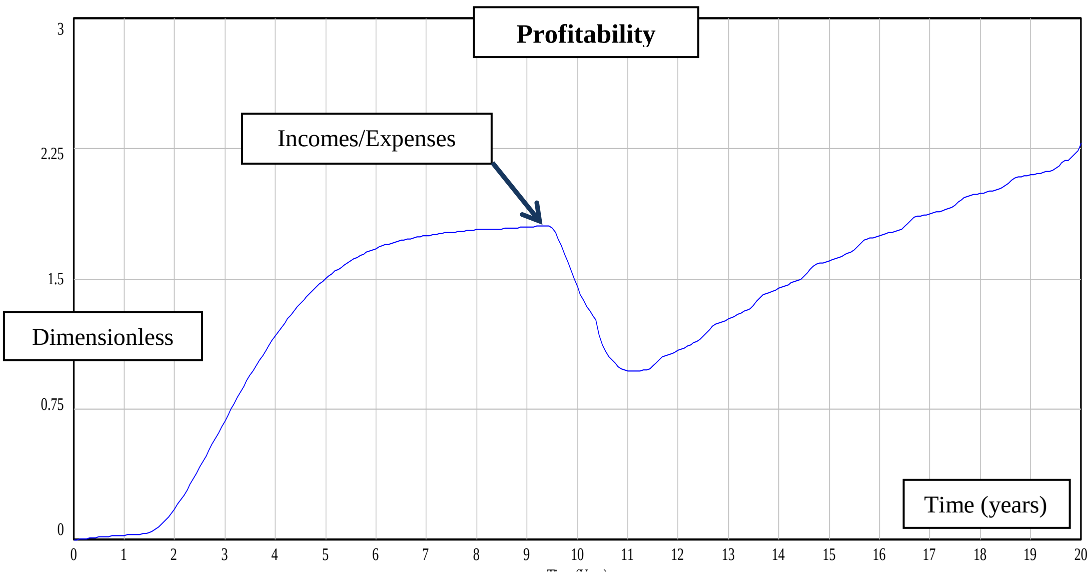

Figure 33: Baseline run – Solaris Profitability

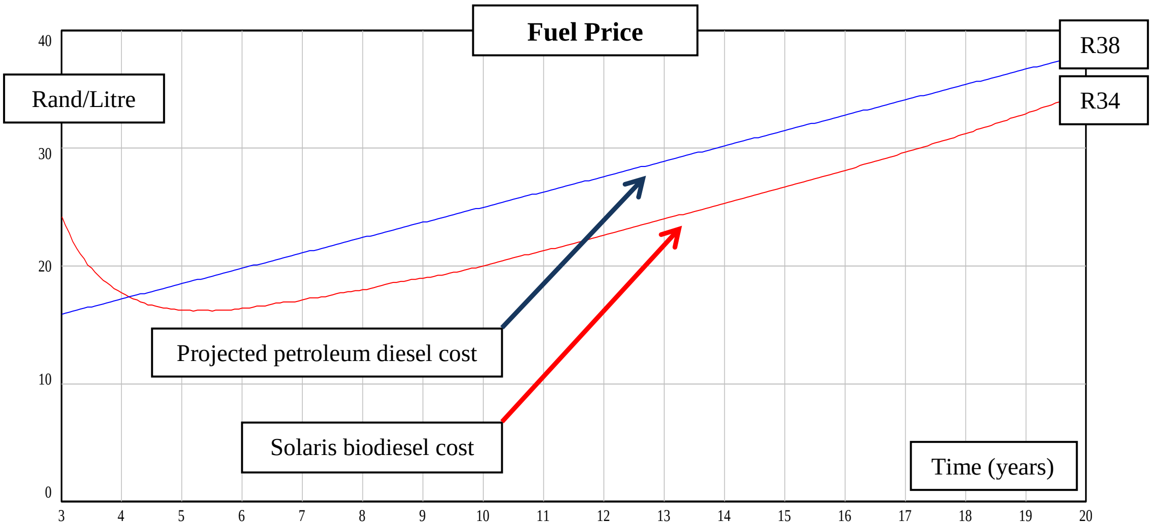

Figure 34: Final baseline run of Loskop Solaris Vensim model showing price projection of petroleum diesel and price of Solaris biodiesel

As displayed in Figure 34, at Solaris biodiesel is generally cheaper than the projected petroleum diesel price. Figure 35 shows that following an initial price spike upon the installation of biogas power generation in year 10, the biogas power price drops off and is significantly lower than the projected Eskom tariff by the end of the simulation.

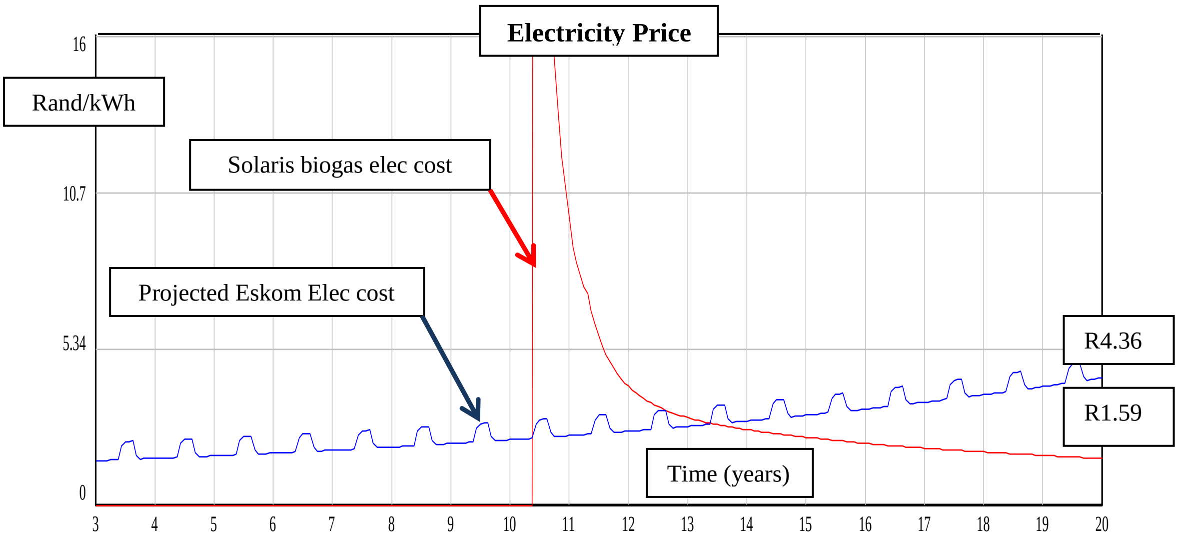

Figure 35: Final baseline run of Loskop Solaris Vensim model showing price projection of Eskom Electricty and Solaris biogas power per kWh

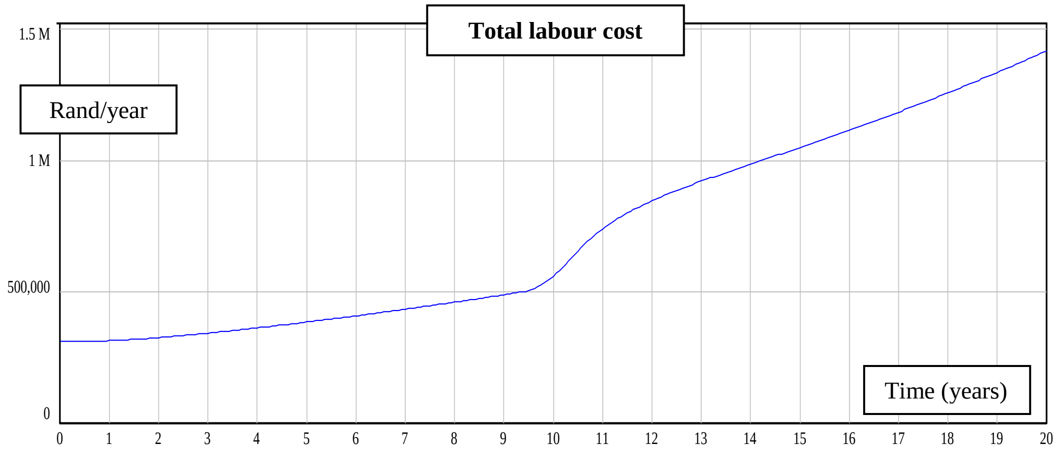

Figure 36: Final baseline run of Loskop Solaris Vensim model showing total labour expense for processing plants

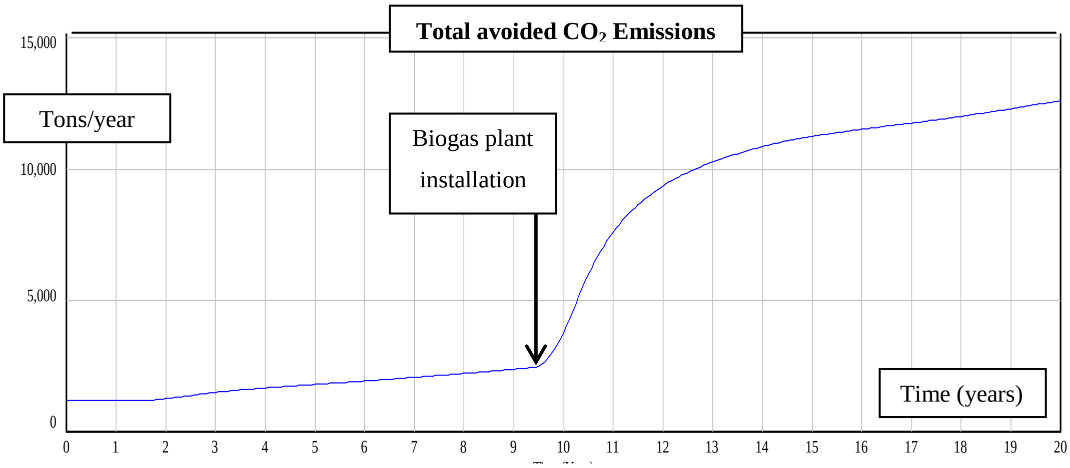

Figure 37: Final baseline run of Loskop Solaris model showing total avoided CO2 emissions

At the end of the 20 year simulation period, the Baseline scenario necessitates 6 full time employees to run the pressing plants, biodiesel plants and biogas power plants respectively. Figure 36 displays the full labour cost associated with the employment of the skilled and unskilled employee required over the period. This cost increases over time both due to inflation as well as with an increase in required work-force due to capacity additions. Figure 37 demonstrates the dramatic effect that implementing biogas power generation in simulation year 13 has on the total avoided CO_2 emissions of the system.

General Baseline observations following 20 years:

- Land allocation increased from 100 to 255 Ha, however it takes 5 years until land allocation increases as the project only reached break-even at this point
- 17.5% electricity independence and 10.9% fuel independence
- Profitability mostly between 1 and 1.7
- Profit per hectare reached only between year 6 and 7, which corresponds to land allocation increase
- 6 permanent employees hired
- Biodiesel generally cheaper than petroleum diesel projection
- Biogas power becomes cheaper than the Eskom power projection

9.2.2 Scenario 1 Comparisons: Seed Yield Variation

Table 12: Scenario 1- demonstrating the effect of a range of Solaris seed yields on the model, with and without biogas power generation

Scenario	Initial land allocation	Seed yield per plant	Biogas power	Seed harvests/season
Baseline	100 Ha	50g/harvest	yes	3
Scenario 1a *(yield comparisons)*	Baseline	30g-100g/harvest	Baseline	Baseline
Scenario 1b *(yield comparisons no biogas power)*	Baseline	30g-100g/harvest	no	Baseline

Given that the Baseline run was defined using quite conservative values for certain parameters, it was imperative to engage in sensitivity testing of the model and ascertain what effect changing these parameters would have on the evolution of the system.

According to the Vensim users' guide, manual sensitivity testing involves changing the value of a particular constant and rerunning the simulation. This is then followed by changing the value of that constant again and rerunning the simulation again. This process is then repeated again. Doing this repeatedly allows one to obtain a wide spread of outputs for the system. A multivariate sensitivity simulation (MVSS), also known as a Monte Carlo simulation, allows this procedure to become automated (Ventana Systems, 2007). Thousands of simulations can thus be instantly performed for a range of predefined parameter values.

The graphs generated from the Monte Carlo simulations show confidence bounds for all the output values of a particular variable when the specified parameter is varied. The confidence bounds are reflected as a percentage which is plotted as a particular colour-band on the graph. Scenario 1 made use of Monte Carlo simulations in Vensim to consider the effect of varying the seed yield from 30g to 100g per plant per harvest. The only difference between Scenarios 1a and 1b is the inclusion of biogas power generation. This was done in an effort to understand the viability of the system if only the seed yield is processed. All other parameters according to the Baseline were kept constant.

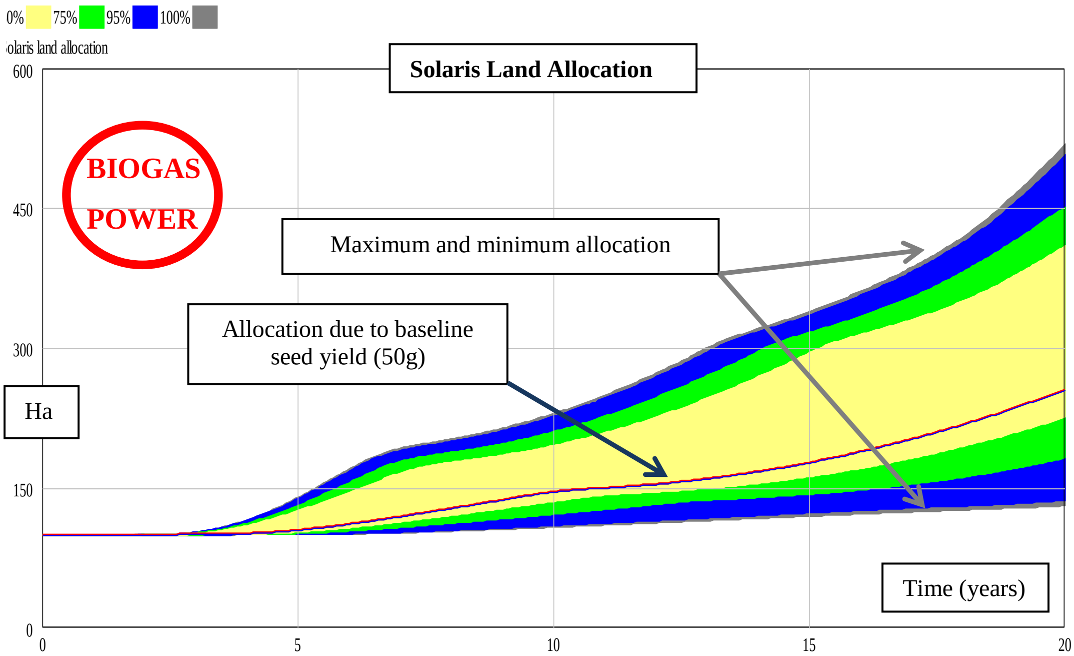

Figure 38: Scenario 1 - Monte Carlo simulation of Solaris land allocation with seed yield ranging between 30g and 100g (biogas power generation included)

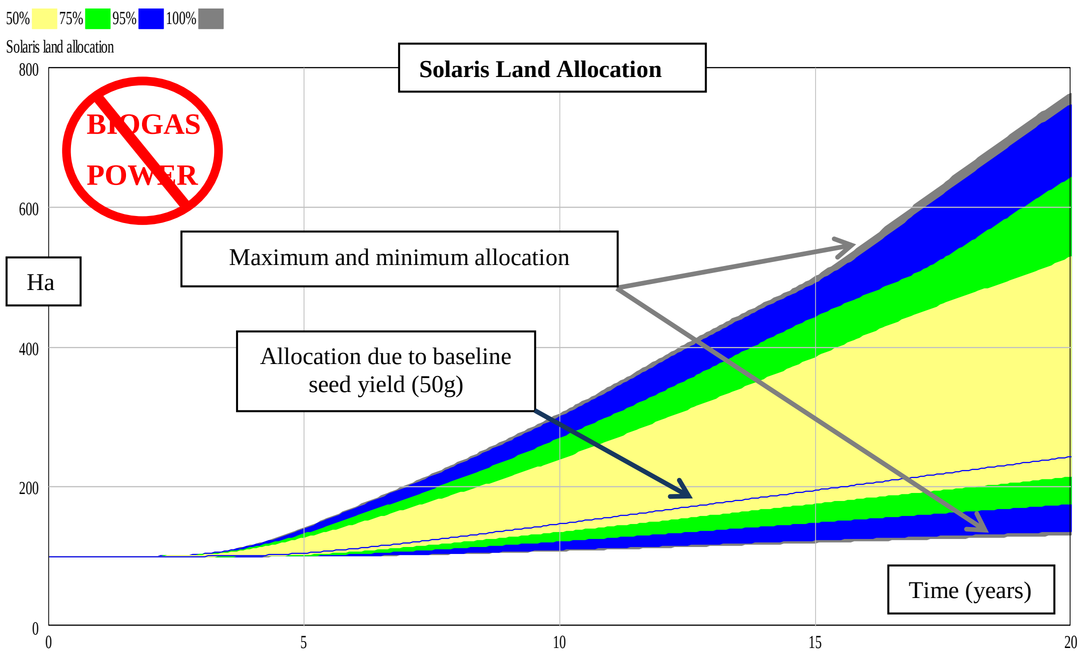

Figure 39: Scenario 1 - Monte Carlo simulation of Solaris Land allocation with seed yield ranging between 30g and 100g (biogas power generation excluded)

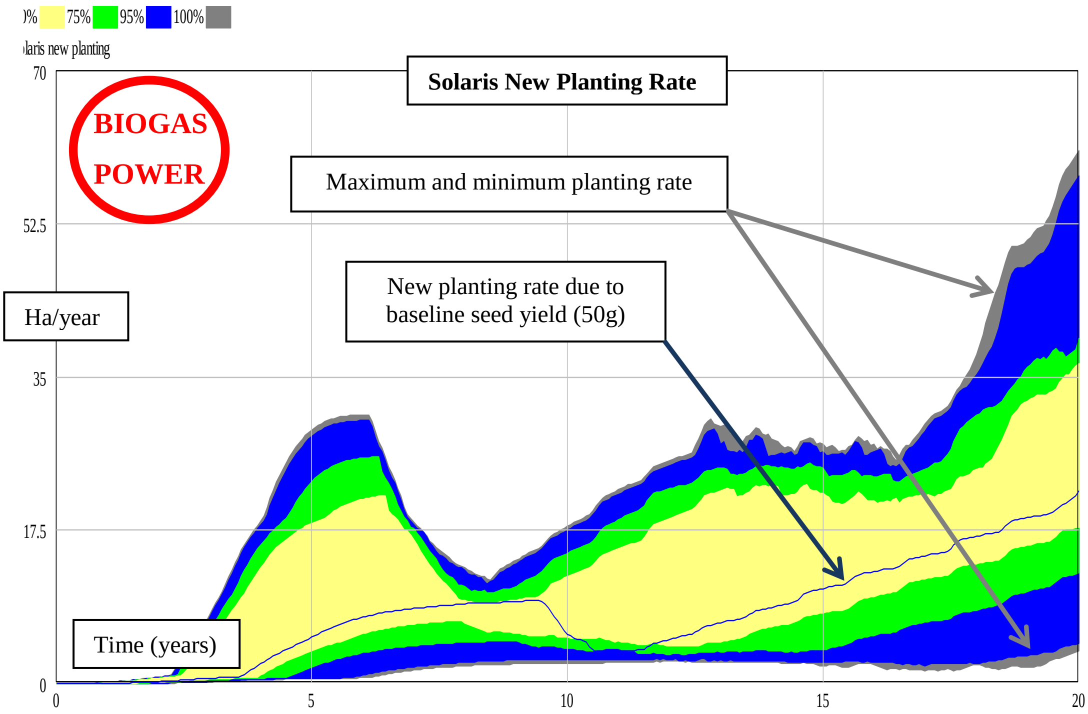

Figure 40: Scenario 1 - Monte Carlo simulation of Solaris new planting rate with seed yield ranging between 30g and 100g (biogas power generation included)

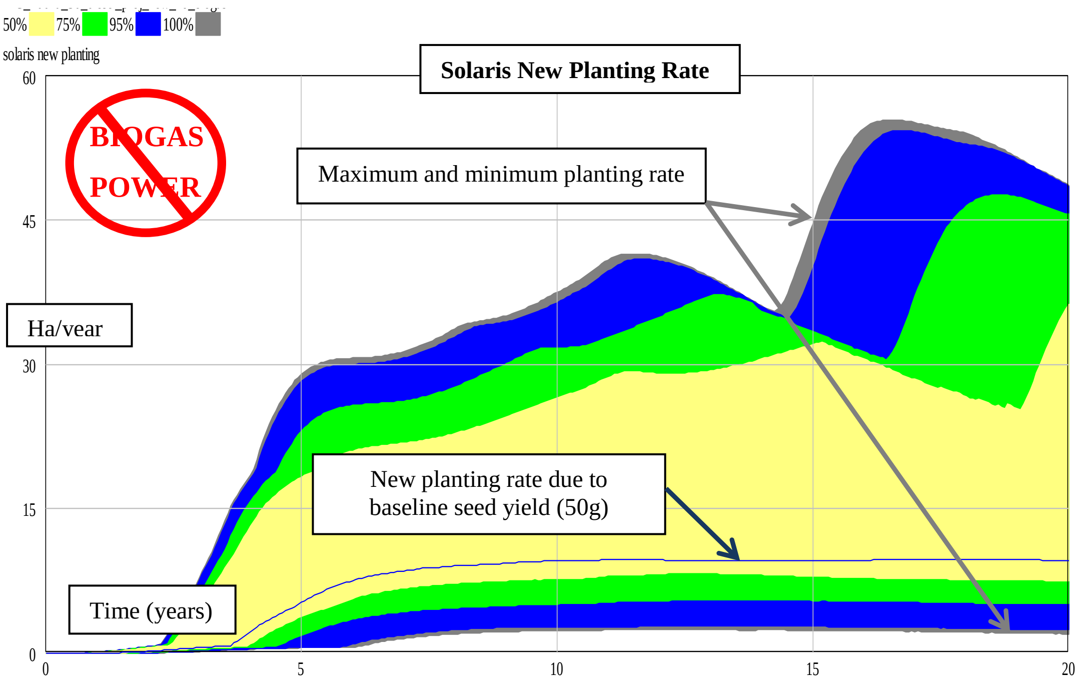

Figure 41: Scenario 1 - Monte Carlo simulation of Solaris new planting rate with seed yield ranging between 30g and 100g per harvest (biogas power generation excluded)

With or without biogas power generation, both Figure 38 and Figure 39 demonstrate the dramatic effect that an increase from the baseline case of 50g to 100g seed yield makes on the land allocation. It is clear that there is a reinforcing effect due to increased profitability and fuel independence driving up the Solaris new planting rate further and making it substantially higher than the baseline case, which is clearly seen in Figure 40 and Figure 41. What is also shown by Figure 40 and Figure 41 is that the inclusion of biogas power generation means the new Solaris planting rate is stunted at various times in comparison to the relatively consistent new Solaris planting rate of the scenario without biogas power generation. This is due to the initial costs associated with implementing biogas power production and its effect on the profitability of the system at those times. However, in the last 2-3 years of Figure 40, a sharp rise in the planting rate suggests that the energy profitability and independence has risen significantly in this time due to the effects of biogas implementation and associated savings by replacing Eskom power. This is corroborated by Figure 42 and Figure 45 showing the substantial increase in electricity independence and profitability respectively over that period.

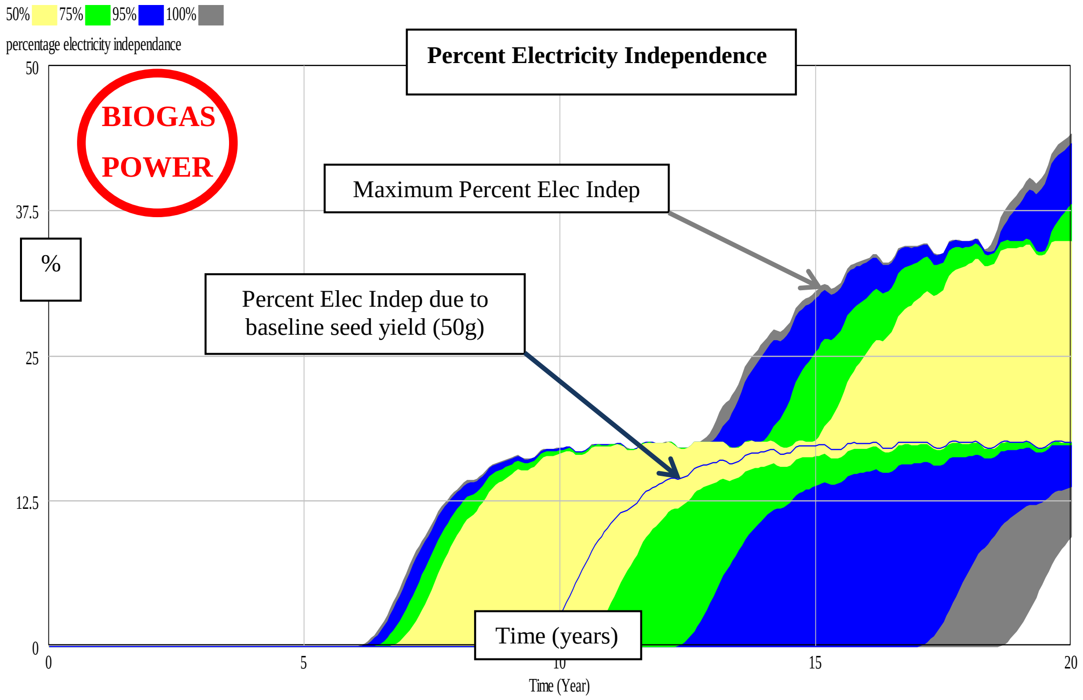

Figure 42: Scenario 1 - Monte Carlo simulation showing Percent Electricity Independence due to Biogas power generation when yields range between 30g and 100g

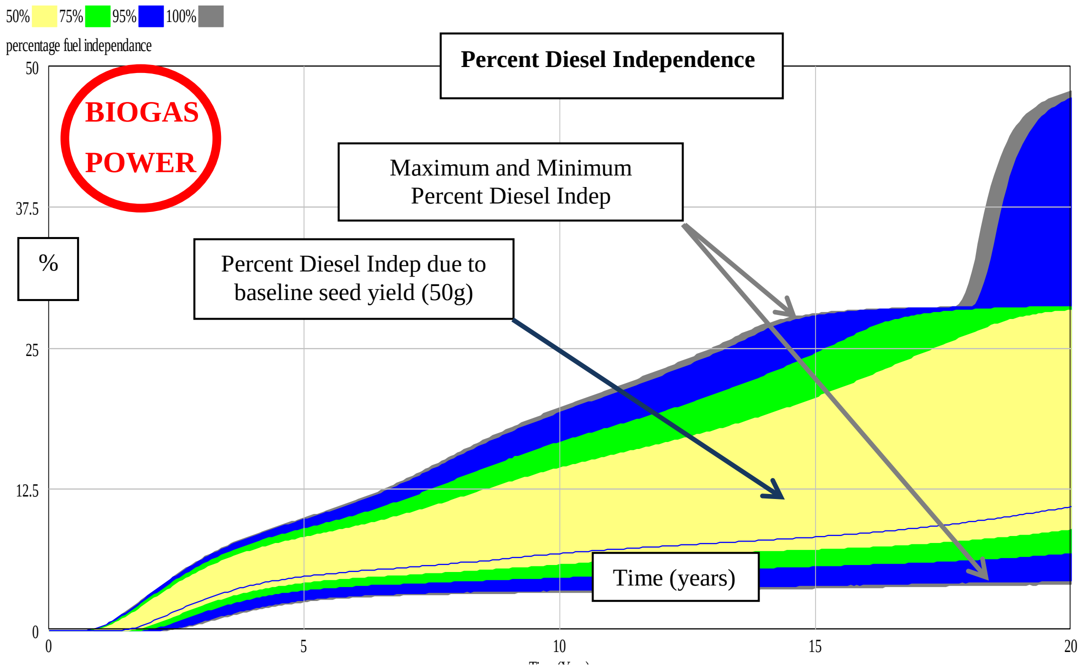

Figure 43: Scenario 1 - Monte Carlo simulation showing Percent Electricity Independence due to Biogas power generation when yields range between 30g and 100g (biogas power generation included)

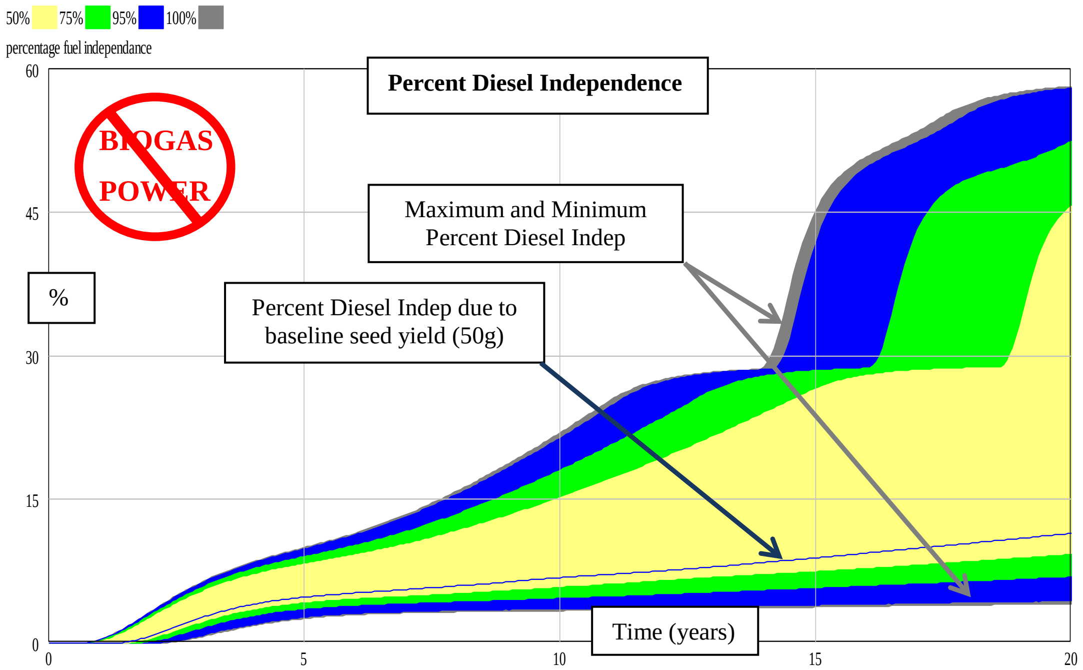

Figure 44: Scenario 1 - Monte Carlo simulation showing Percent Electricity Independence due to Biogas power generation when yields range between 30g and 100g (biogas power generation excluded)

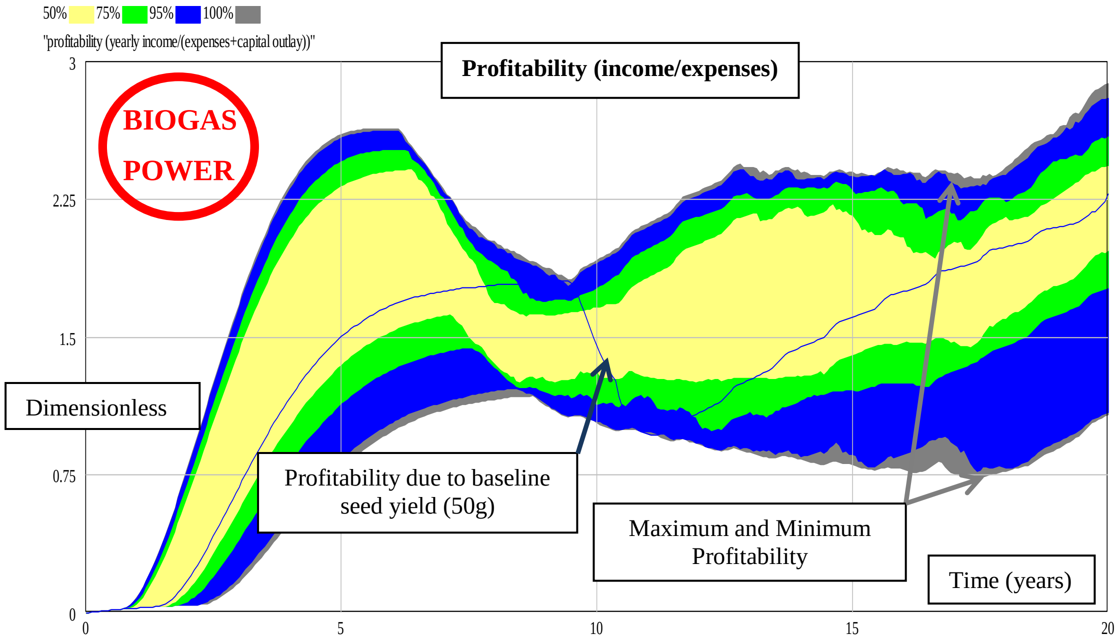

Figure 45: Scenario 1 - Monte Carlo simulation showing Profitability when yields range between 30g and 100g (biogas power generation included)

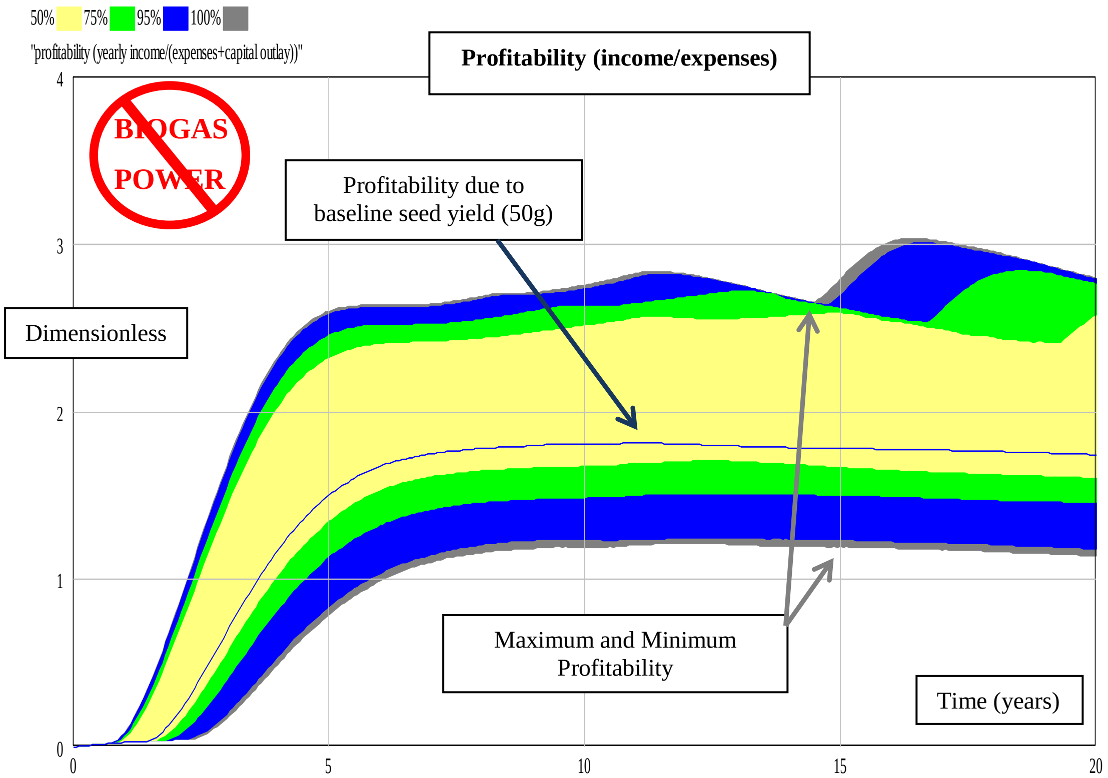

Figure 46: Scenario 1 - Monte Carlo simulation showing Profitability when yields range between 30g and 100g (biogas power generation excluded)

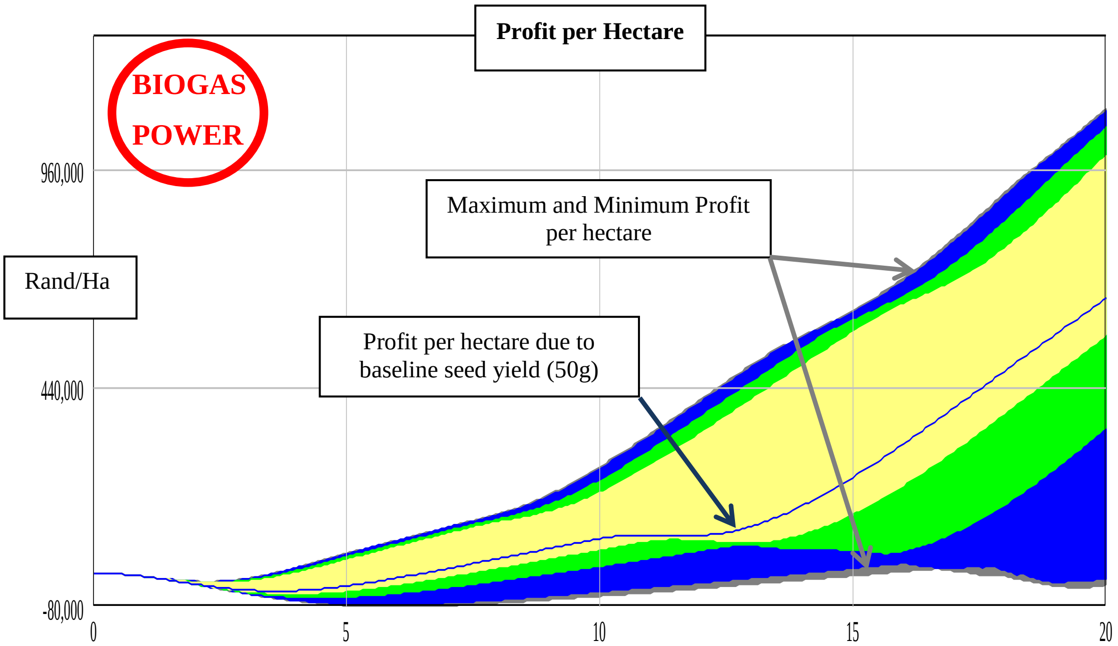

Figure 47: Scenario 1 - Monte Carlo simulation showing Profit per hectare when yields range between 30g and 100g (biogas power generation included)

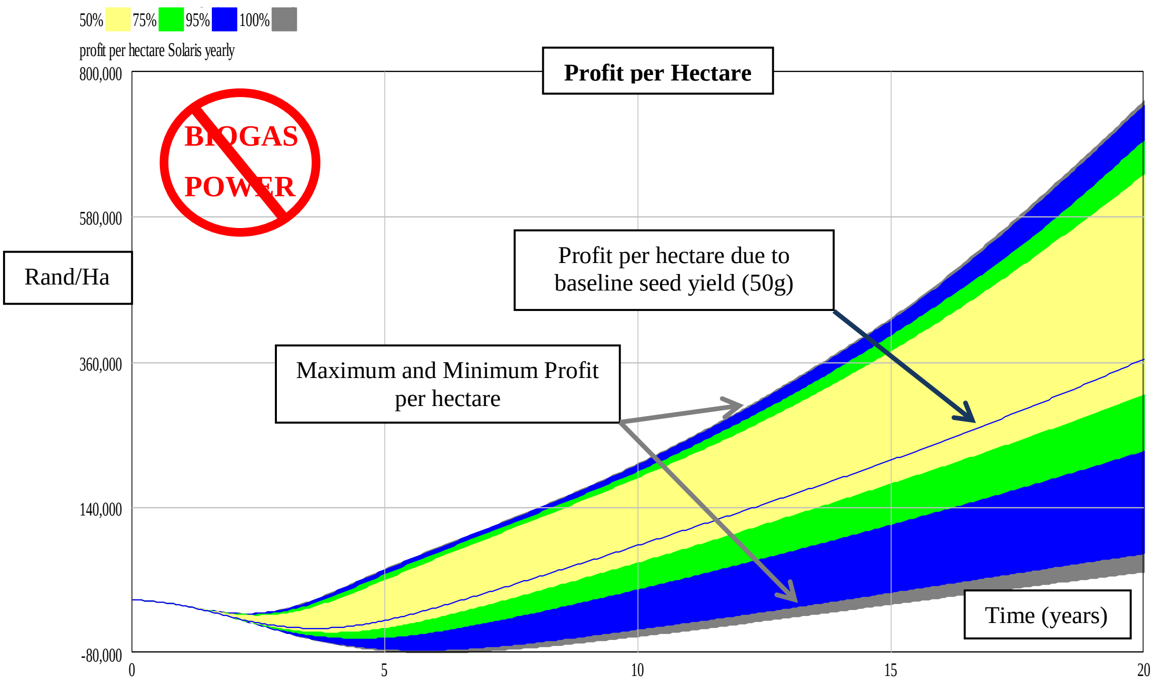

Figure 48: Scenario 1 - Monte Carlo simulation showing Profit per hectare when yields range between 30g and 100g (biogas power generation excluded)

With or without biogas power generation Figure 45, Figure 47 and Figure 48 clearly show that yields of 30g per plant will not suffice to bring about any sort of profitability to the system. At that level of production the system never breaks even.

Ultimately, with favourable yields, the scenario with biogas power generation does end up being the most profitable, as demonstrated in Figure 47 and Figure 48.

However, this is only evident near the end of the 20 year period and so its favourability has to do with a long-term revenue view as well as valuing the associated benefits of independent electricity generation. Figure 49 and Figure 50 enable one to draw a comparison between the range of 'Avoided CO_2 Emissions' resulting from the yield variations tested, both with and without biogas power generation. It is apparent that the largest contributing factor to avoided emissions is due to replacing Eskom power with biogas power.

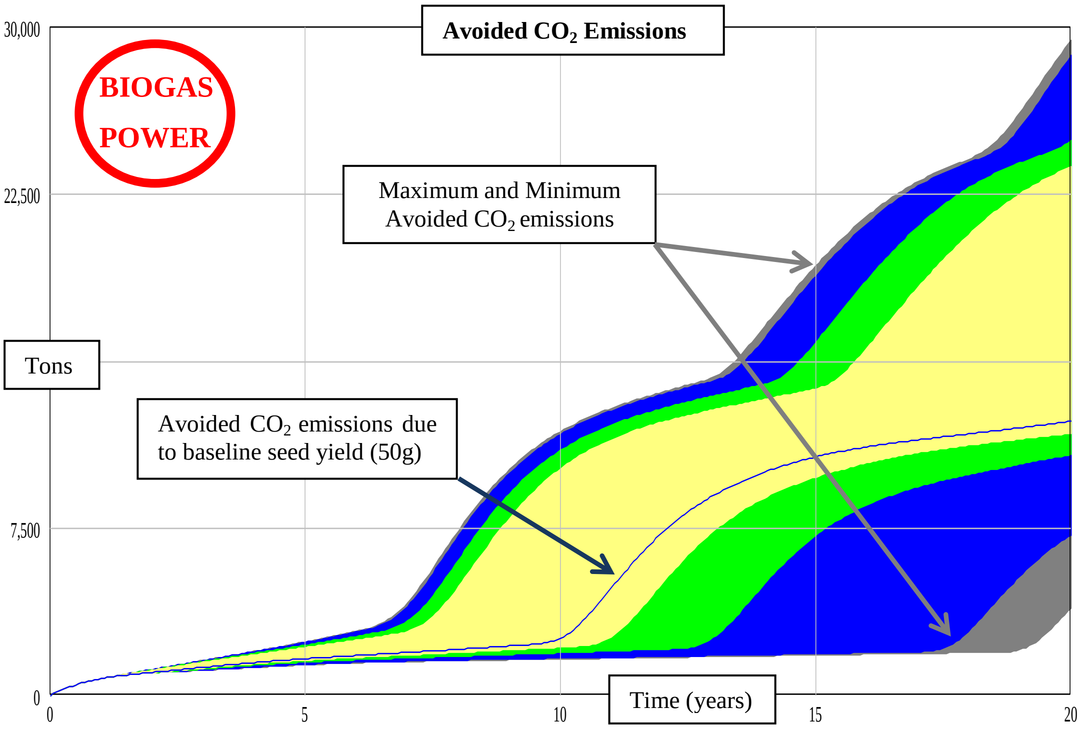

Figure 49: Scenario 1 - Monte Carlo simulation showing avoided CO_2 emissions when yields range between 30g and 100g (biogas power generation included)

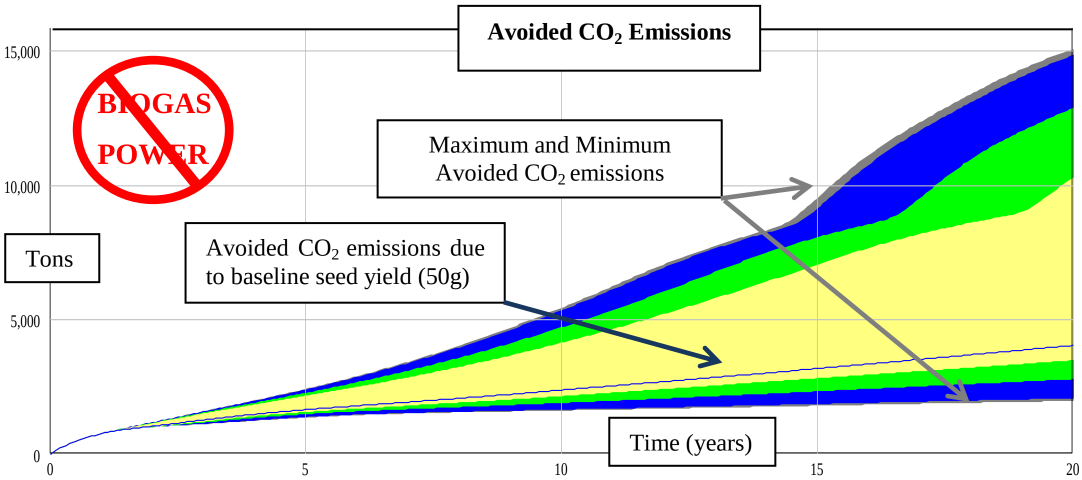

Figure 50: Scenario 1 - Monte Carlo simulation showing avoided CO_2 emissions when yields range between 30g and 100g (biogas power generation excluded)

General Scenario 1 observations after a 20 year period

See Table 13 below for general comparisons, but for 100g seed yield per plant including biogas power:

- Approximately five-fold increase in land allocation
- 44% electricity independence, 47.7% fuel independence
- Profitability mostly between 2.5 and 2.5
- Profit per hectare evident after year 4, and increases exponentially in comparison to baseline case
- Increased energy profitability and independence result in further increases in land and hence further increases in profitability and independence
- 18 permanent employees hired
- At this seed yield, the Solaris biodiesel is generally cheaper than the projected petroleum diesel price biodiesel
- Ultimately, a higher seed yield and biogas power generation are the main driving factors for increased energy profit, energy independence, emissions avoidance and job creation. Shorter term profit benefits however are realised when exclusively processing the Solaris seed.

Table 13: Scenario 1 - Miscellaneous comparisons between different yield values, with and without biogas power generation

	30g	**50g**	**100g**
Land Allocation			
Biogas	129ha	255ha	520ha
No Biogas	129ha	243ha	764ha
Diesel Independence			
Biogas	3.9%	10.9%	47.7%
No Biogas	3.9%	11.4%	58.1%
Electricity Independence			
Biogas	6%	17.5%	44%
No Biogas	-	-	-
Permanent Employees			
Biogas	6	6	18
No Biogas	4	4	18
Avoided Emissions			
Biogas	2 370 tons	12 300 tons	29 400 tons
No Biogas	1 970 tons	4 040 tons	15 100 tons

9.2.3 Scenario Comparisons 2: Initial land allocation variation

Table 14: Scenario 2 - demonstrating the effect that increased initial land allocation makes on the model, with and without biogas power generation

Scenario	**Initial land allocation**	**Seed yield per plant**	**Biogas power**	**Seed harvests/season**
Baseline	100 Ha	50g/harvest	yes	3
Scenario 2 *a* *(Land boost)*	500Ha	100g/harvest	Baseline	Baseline
Scenario 2 *b* *(Land boost without biogas power)*	500Ha	100g/harvest	no	Baseline

The purpose of Scenario 2a is to understand what land allocation would allow the system to reach a state of viable energy independence within the simulation timeframe. This would help provide an understanding of what land allocation of Classic Tobacco could remain at this point as well as what energy independence means for the other social, economic and environmental goals of the system at this juncture. Due to this seed yields were set at a favourable, yet achievable, value of 100g per plant per harvest and the simulations started with a Solaris land allocation of 500ha. Without biogas power electricity independence cannot be reached, however, running Scenario 2b allows us to identify how much of an impact utilising the biomass for electricity generation has on various outputs.

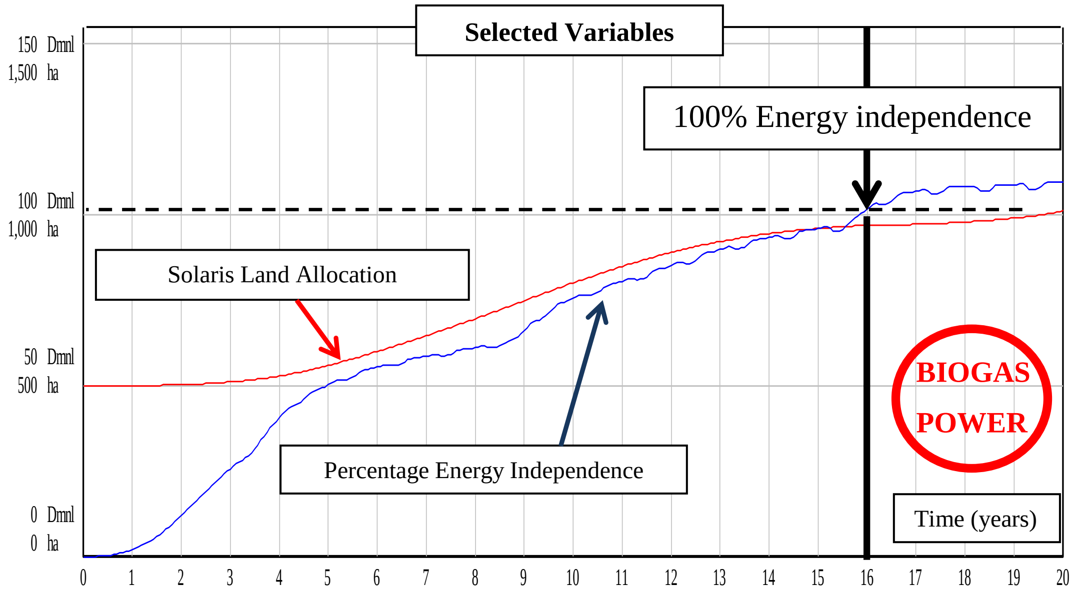

Figure 51: Scenario 2a – Solaris land allocation and energy independence

If the land allocation is able to begin at 500Ha then, as shown in Figure 51, full electricity and fuel independence can be achieved when 968Ha Solaris land allocation is reached

Further, Figure 52 demonstrates that with the same parameters biogas power generation becomes cheaper than Eskom around year 5. Similarly Solaris biodiesel becomes cheaper than the projected petroleum diesel price around year 2 and continues to maintain this throughout the simulation, as Figure 53 indicates.

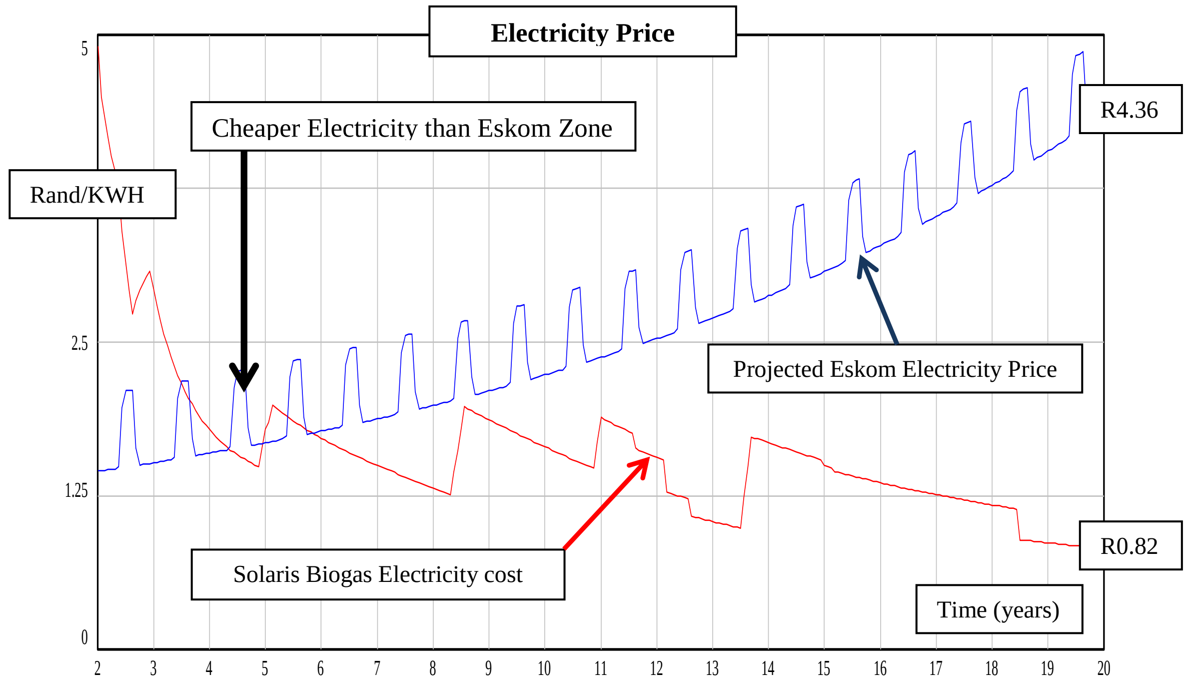

Figure 52: Scenario 2a – Solaris power price versus Eskom power price (when seed yield is 100g per plant per harvest)

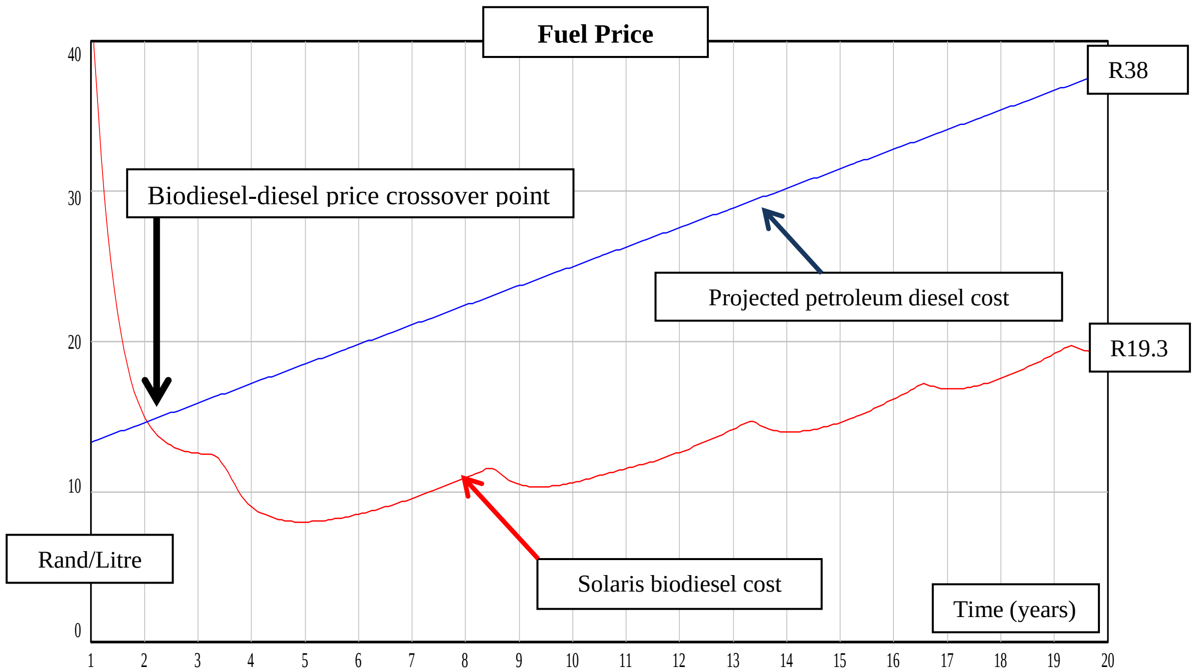

Figure 53: Scenario 2b - Solaris biodiesel price versus Petroleum diesel price (when seed yield is 100g per plant per harvest)

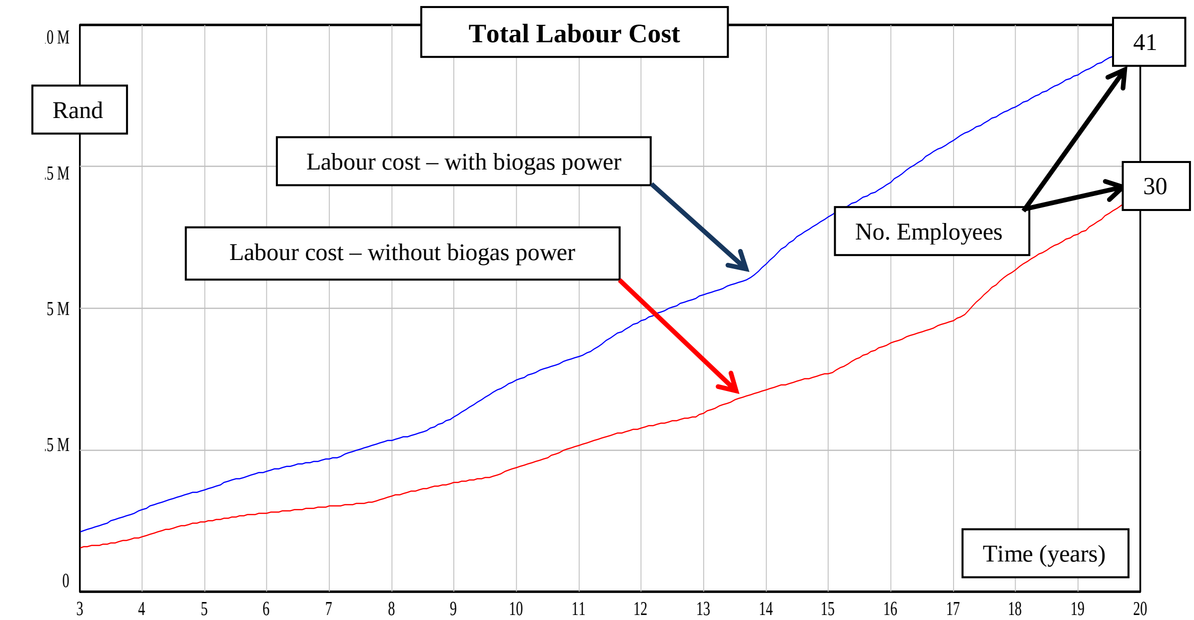

Figure 54: Scenario 2 - total processing labour force expense comparison

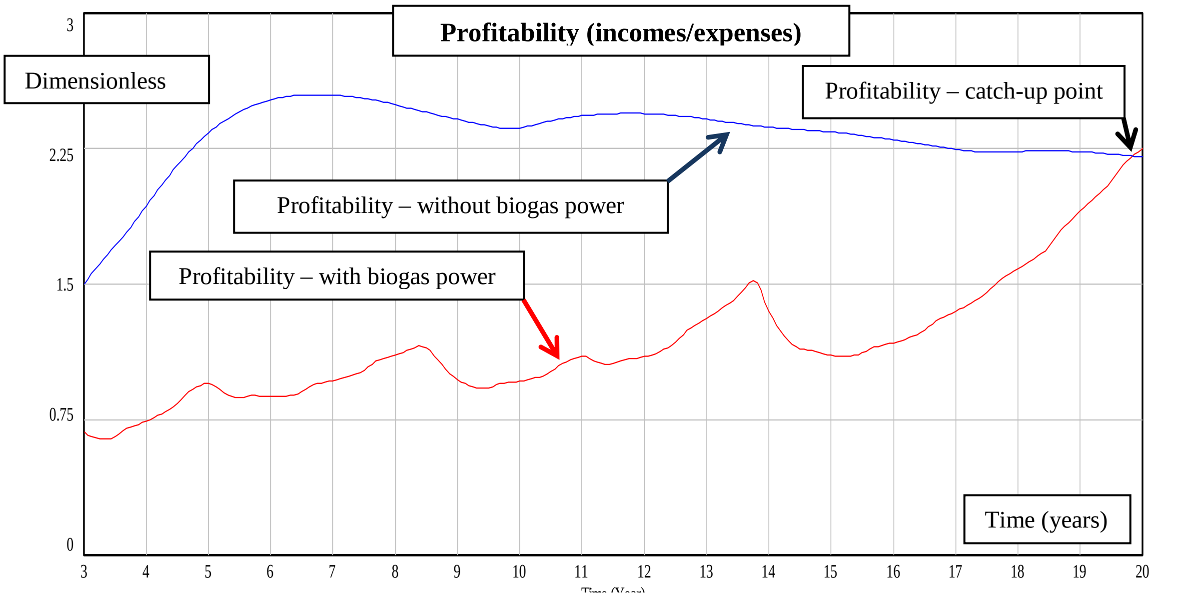

Figure 55: Scenario 2 – Solaris profitability comparison with and without biogas power

Whilst Figure 55 shows that the profitability of Scenario 2a, with biogas power generation, is lower than Scenario 2b for most of the simulation period, it does catch-up towards the end. However, delayed profitability of 2a is countered by the full energy independence as well as vastly increased permanent employment and avoided emissions as displayed in

Figure 54 and Figure 56 respectively. To give an indication of how the initial land allocation affects profitability, a sensitivity analysis was conducted using a range of values between 50-500ha. Figure 57demonstrates that the initial land allocation does affect the profitability range quite substantially and it is believed that this is because a larger initial allocation requires a much larger initial investment in processing equipment and hence more substantial loan repayments.

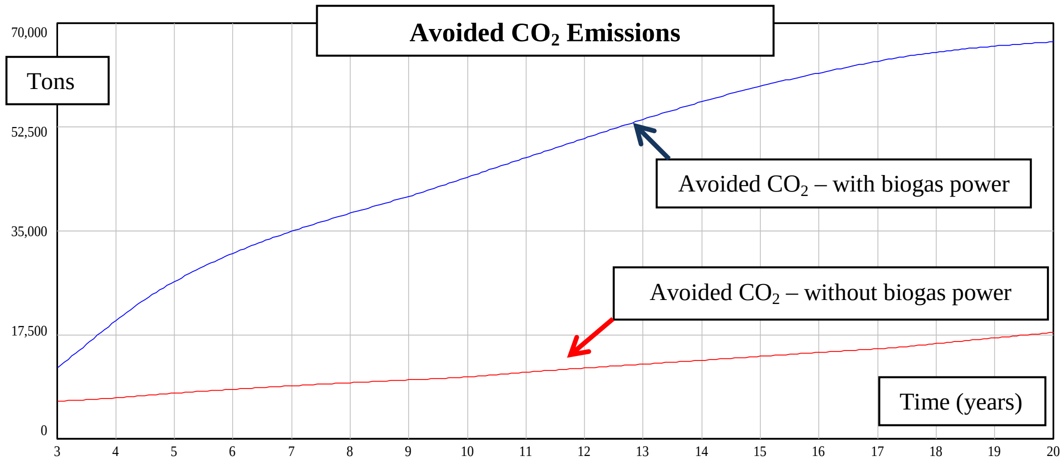

Figure 56: Scenario 2 – Solaris avoided CO2 emissions comparison

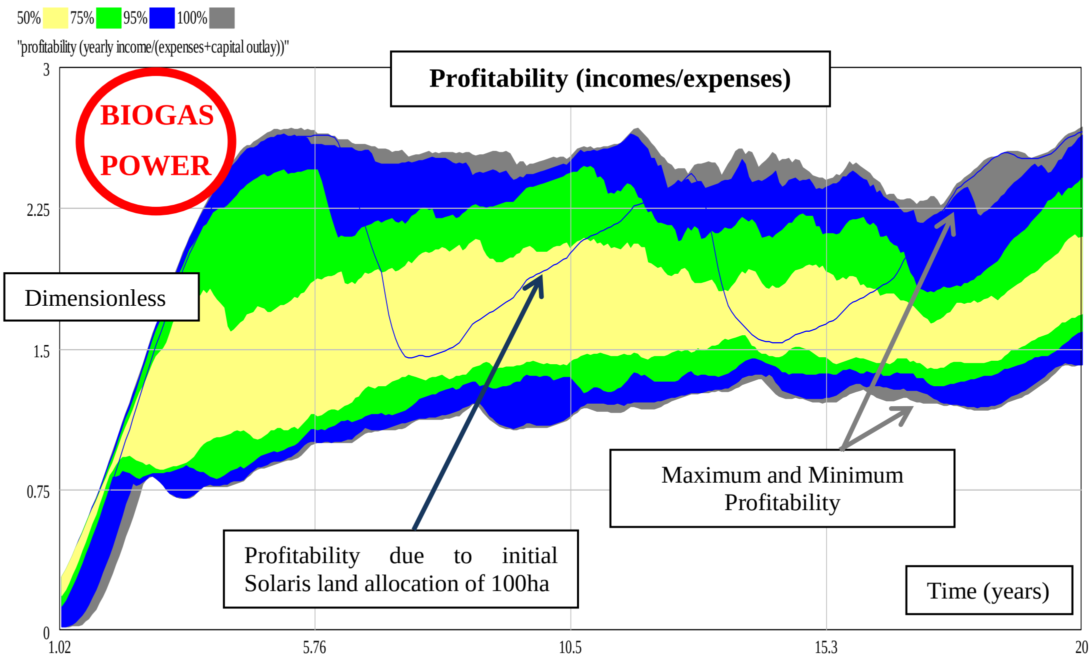

Figure 57: Scenario 2a - Monte Carlo simulation showing profitability when initial Solaris land allocation ranges between 50 and 500ha (biogas power generation included)

General Scenario 2 observations after a 20 year period

- 100% Electricity and Fuel independence reached at 968 Ha Solaris land allocation
- At year 2 biodiesel cheaper than petroleum diesel
- At year 5 biogas power cheaper than Eskom power
- Profitability and profits are higher earlier when no biogas power plants are set up (due to avoided initial large capital outlay) but catch-up towards the end of the simulation period

- Inclusion of biogas power may have lower profitability initially but meets energy independence goals, has substantially higher employment creation as well as vastly higher avoided emissions

10 Conclusions and Recommendations for future work

One of the primary goals of this study was to demonstrate that the use of Systems Thinking is integral to assessing the viability, whilst also pre-empting possible failure, of introducing a new biodiesel feedstock into South Africa. It is believed that the Systems Thinking process followed as well as the outcomes of the System Dynamics modelling has achieved this goal.

The System Dynamics approach as enabled us to understand, for Solaris, what range of seed yields, initial land allocation and combination of diesel and electricity generation is best in terms of meeting the various desires of the community and country.

Building the model to allow for a modular increase in land allocation, seed pressing capacity, biodiesel production and biogas power generation means that although economies of scale are not initially able to be achieved in terms of costing, the system only grows in accordance with the capabilities of the system and relative to the needs of the community in terms of energy independence and profitability. This approach has thus allowed for an understanding of the trade-offs that need to be made between earlier profitability or earlier increases in energy independence, employment and avoided emissions. Due to this a reasoned decision can be made as the optimal initial land allocation as well as at what point (if any) biogas power generation should be implemented.

The projected increases in national fuel and electricity supply suggest that there will be significant value in implementing local cultivation and processing for diesel and power generation. Given the concerns of many of the community with regards to the sustainability of their current crop choices should the prices, as well as consistency of supply, rise as predicted, it seems integral for food security that farming communities are able to take control of their own energy needs. However, should the projections be incorrect, resulting in it being substantially more profitable to use nationally supplied petroleum diesel and electricity, a similar abandonment of biofuel production as we experienced in the 1970s in South Africa could occur. However, given that the proposed implementation of mandatory blending of biofuels in South Africa would guarantee a market and price, price volatility of fuel could be overlooked.

The further benefits of the modular approach of local processing expansions are to do with employment and avoided emissions. It has been argued that the desires of the 2007 South African Biofuels Strategy in terms of dealing with societal inequalities are not going to be addressed by handing out low level employment. Rural development and upliftment can only come about if citizens are given an opportunity to better their situation by means of gaining skills and having a stake in the businesses they are involved in.

Whilst this model was based on the situation of an established commercial farming community it is thought that this is a good starting point to address the needs at a rural level. Given the experience of the commercial farmers (particularly in the Loskop area with Tobacco cultivation) allowing the adoption of the local cultivation and processing to begin in this community can provide resources for the training and mentoring of rural farmers such that it can be implemented sustainably where it is needed. However, the environmental effects at a rural level, especially if previously uncultivated land is considered for use, must also be considered.

Whilst much was gained from the results of the current model there are many useful modifications can be done to further enrich its outcomes. Planned future work will consider:

- Including other feedstock types into the model for comparison
- Including the market effects of Classic Tobacco
- Diesel price volatility
- Further changes to the Eskom pricing calculations to take into account rural line fees
- Environmental effects if Solaris is grown on land not currently being used for Classic Tobacco (or any other cultivation at all)
- Determining the land and resource requirements if Solaris has to meet the current 2% blending goals of South Africa
- Further understanding what optimisations in the cultivation and processing will have the largest effect on viability
- Understanding to what extent the press cake can meet the local community's animal feed requirements

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Appendix A

Visualisation of the Vensim Loskop Solaris System Dynamics model

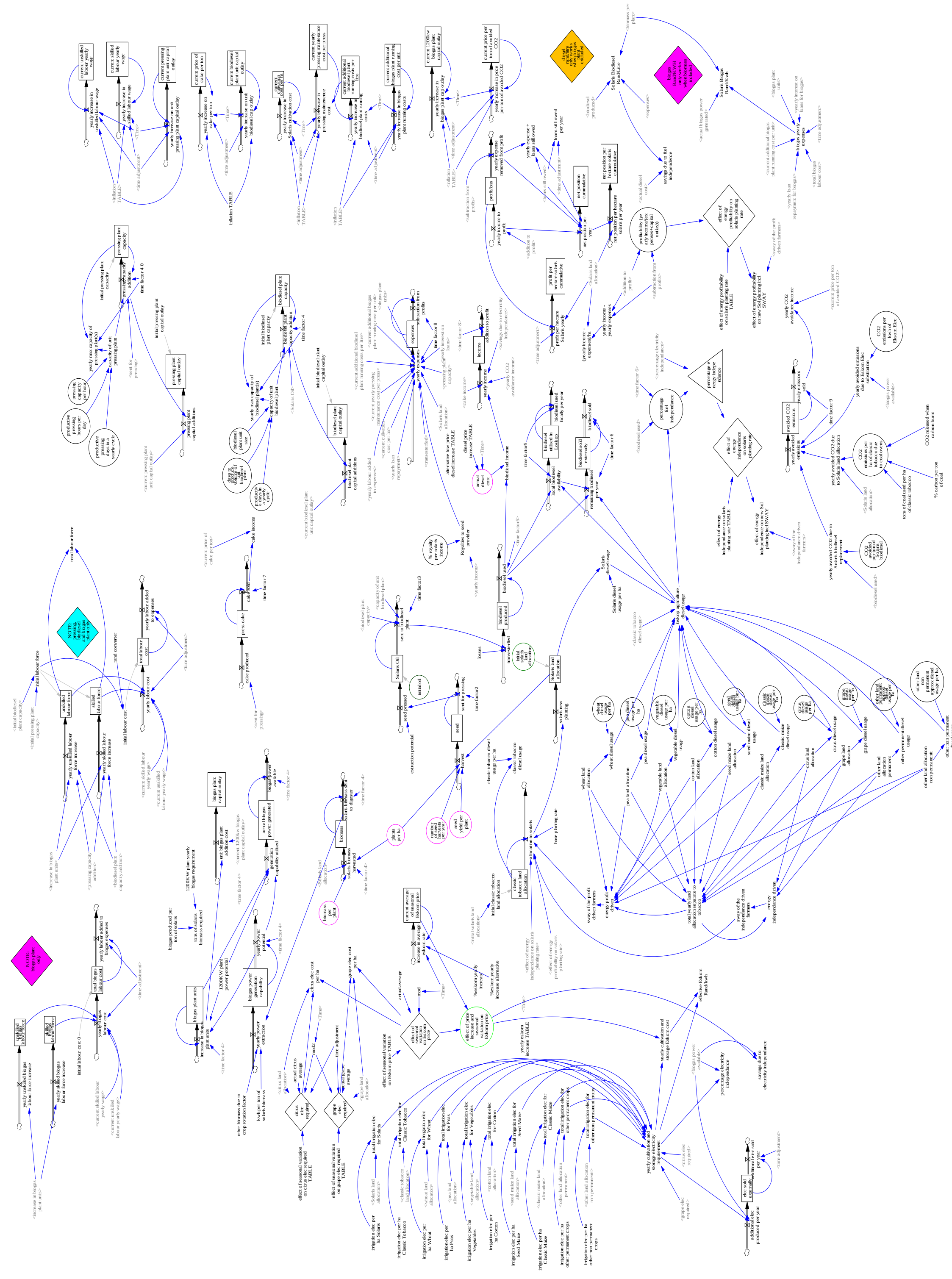

Figure 58: Overview illustration of the main Loskop Solaris Vensim model

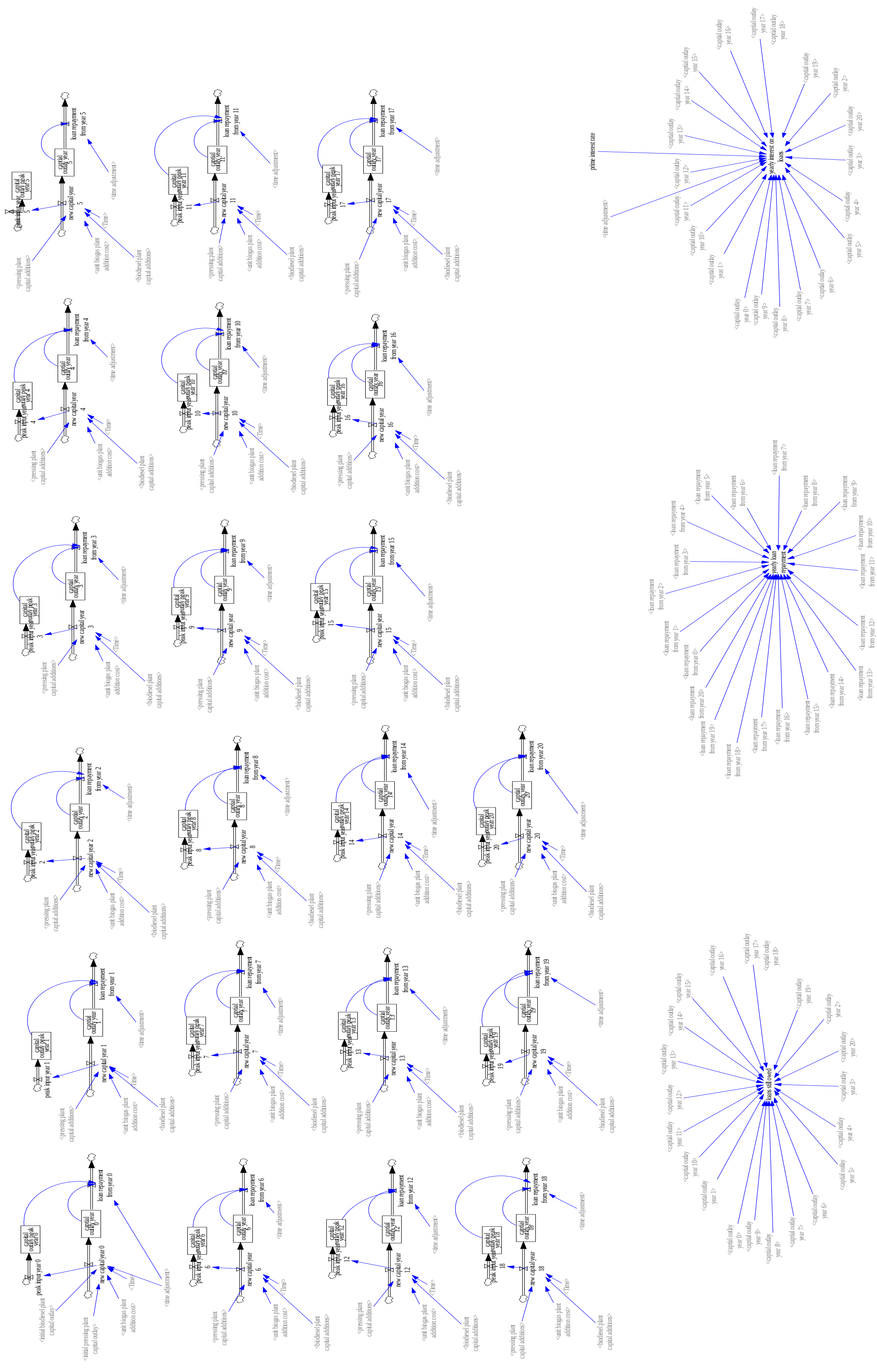

Figure 59: Overview illustration of a sub-model in the Loskop Solaris Vensim model

Appendix B

Calculations

Emissions avoidance due to prevention of coal combustion

When coal is burnt, the carbon content combines with oxygen to form the greenhouse gas carbon dioxide (CO_2). Using data from the USA Energy information agency, we assuming that he grade of coal being used in Loskop has a carbon content of 80%. Further, we assume that, when combusted, 1 unit of carbon combines with 2.667 units of oxygen to produce 3.667 units of carbon dioxide (B.D. Hong, 1994). Based on this, the amount of CO_2 produced per ton of coal is as follows:

Table 15: Determination of carbon dioxide released per ton of coal combusted

Coal (ton)	Carbon (%)	CO_2 (ton)
1	80	2.9336

Emissions avoided due to petroleum diesel being substituted with biodiesel

According to the research conducted, biodiesel and petroleum diesel release a certain amount of carbon dioxide (CO_2) per mega joule (MJ) of energy released from each respective fuel (A.L Stephenson, 2010). Using these values as well as the values given for energy released per kilogram of each fuel type, shown in columns 1 and 2 of both Table 16 and Table 17, the amount of tons CO_2 per litre of fuel was calculated.

Table 16: Determination of carbon dioxide released per litre of biodiesel

MJ/Kg of biodiesel	Kg CO_2/MJ Biodiesel	Kg CO_2/Kg Biodiesel	Kg CO_2/litre Biodiesel
37.2	0.004	0.1488	0.123802

Table 17: Determination of carbon dioxide released per litre of petroleum diesel

MJ/Kg of Diesel	Kg CO_2/MJ Diesel	Kg CO_2/Kg Diesel	Kg CO_2/litre Diesel
43.1	0.104	4.4824	3.729357

If one subtracts the CO_2 emissions of biodiesel usage per litre from the CO_2 emissions of petroleum usage per litre, it can be determined what the avoided emissions per litre are if such a fuel substitution is made. This amounts to approximately: 3.6 avoided kgs of CO2/litre of biodiesel used.

Appendix C

Data from preliminary Solaris trials in Loskop 2012/13

Table 18: Standardised sample plants taken in March 2013 to determine average yield capability (individually processed) from Solaris 2012-2013 Loskop preliminary trial

Plant Number	Number of Capsules	Dried Weight Inflorescence (g)	Dried Weight - Seed per plant (g)
1	211	122	54
2	364	154	70
3	223	106	44
4	215	96	42
5	351	184	76
6	242	142	60
7	287	missing	60
8	244	112	38
9	340	158	74
10	529	258	142
Average	**300.6 capsules**	**133.2 grams**	**66 grams**

Figure 60: Region, 264m^2 in area, where 400 plants were harvested and processed (collectively processed) from Solaris 2012-2013 Loskop preliminary trial

Table 19: Seed yield of 264m^2 area with 400 plants harvested

Area Harvested	Number of Plants	Dried Weight of Seed (kg) **	Seed per plant (g)***
264 m^2	400	20	50

*** Scale only able to take weight in whole kilograms*

****assumed 10% seed loss due to crusher and portion of seed lost on shed floor and mixed with dirt*

Figure 61: Standard-sized Solaris plants (without inflorescences) harvested to ascertain average biomass yields expected.

The average weight of a freshly harvested inflorescence from samples taken in this trial was **0.439 kg**.

Table 20: Solaris biomass average yields obtained from harvesting 3 standard plants (without inflorescences)

Plant number	**Weight (Kg)**	**height (m)**
1	1.366	1.32
2	0.908	1.28
3	0.962	1.34
Average	**1.079**	**1.31**

Appendix D

Stocks, flows and auxiliary variables

Table 21: Endogenous, Exogenous and Excluded Variables of the Loskop Solaris System Dynamics Model

Endogenous			**Exogenous**	**Excluded**
Stocks	***Flows***	***Auxiliary***	***Parameters***	
Solaris Land Allocation	-Solaris new planting rate	-Allocation of Classic Tobacco land to Solaris -Avoided CO2 emissions due to allocation from Classic to Solaris -Effect of energy independence on Solaris planting rate -Effect of energy profitability on Solaris planting rate -Sway of the energy independence driven farmers -Sway of the energy profitability farmers	-Initial Classic Tobacco land (max available to Solaris)	-Effect of Classic Tobacco market
Seed	-Harvest -Sent for Pressing		-Plants per hectare -Number of harvests per season -Seed yield per plant per harvest	-Seed losses during drying and processing -Experience of farmer affecting yields -biomass
Pressing Plant Capacity	-Pressing Capacity Addition	-Sent for Pressing -Yearly Max Capacity of Pressing Plant(s)	-Productive Pressing Hours in a Day -Pressing Capacity per Hour -Productive Pressing Days in a Yearly Cycle	
Pressing Plant Capital Outlay	-Pressing plant Capital Addition	-Pressing Capital Addition -Year	-Current Pressing Plant Unit Capital Outlay	

Solaris Oil	-Seed pressed -Sent to biodiesel plant	-Biodiesel plant capacity	-Extraction potential	
Biodiesel	-Transestified -Biodiesel used		loses	
Biodiesel Plant Capacity	-Biodiesel Plant Capacity Addition	-Stock of Solaris Oil	-Capacity of unit biodiesel plant	
Biodiesel Plant Capital Outlay	-Capital additions	-Capacity Addition	-Cost of unit biodiesel plant	
Press Cake	-Cake produced -Cake Sold	-Seed pressed		
Expenses	-Yearly expenses -Subtract from profits	-Sent for pressing -Solaris land allocation -Profitability	-Cost of pressing per ton -Cost of cultivation per hectare -Additional biodiesel plant running costs per litre	-Storage and transport -Cost of avoided emissions determination/consulting
Income	-Yearly income -Addition to profit	-Biodiesel used -Cake Sold -Yearly CO2 avoidance income Profitability	-Actual diesel price -Cake price per ton -Price per ton of avoided CO2	
Profit	-Yearly income/expenses/capital outlay	-Profitability		
Biodiesel Utilised in Loskop	-Local biodiesel -availability Biodiesel used locally per year	-Loskop agriculture diesel usage -Biodiesel used -Percentage of fuel independence		
Biodiesel Sold externally	-Remaining biodiesel per year -Biodiesel sold	-Loskop agriculture diesel usage -Biodiesel used	-Actual diesel price	

Profit	-Yearly income/expenses/capital outlay	-Profitability		
Biomass	Solaris Biomass Harvested Solaris Biomass sent to digester	Solaris Land Allocation	-Plants per hectare - Biomass per plant	
Biomass power generation capability	-Yearly power extracted -Yearly power potential	-Solaris biomass sent to digester	-kWh per ton of Solaris biomass -Other biomass due to crop rotation factor	
Biogas plant units	-Increase in biogas plant units	-Yearly power potential	-1200kW plant potential	
Actual Biogas power generated	-Generation capability utilised -Biogas power available	-Biogas plant units -Yearly power potential	--1200kW plant potential	

Table 22: Additional endogenous, exogenous and excluded variables of the Loskop Solaris System Dynamics Model following the results of the System Dynamics workshop

Endogenous			**Exogenous**	**Excluded**
Stocks	***Flows***	***Auxiliary***	***Parameters***	
Capital Outlay year (1-20)	-New Capital Outlay year (1-20) -Loan repayment from year (1-20)	-Loans still owed -Yearly loan repayment -Yearly interest on loans	-Pressing plant capital additions -Unit biogas plant additional cost -Biodiesel plant capital additions -Prime interest rate	

Skilled labour force	-Yearly skilled labour force increase	-Increase in biogas plant units -Pressing capacity addition -Biodiesel plant capacity addition -Total labour force		
Unskilled labour force	-Yearly unskilled labour force increase	-Increase in biogas plant units -Pressing capacity addition -Biodiesel plant capacity addition -Total labour force		
Total labour cost	-Yearly labour cost -Yearly labour cost added to expenses	- Skilled labour force - Unskilled labour force	-Current skilled labour daily wage -Current unskilled labour daily wage	
Profit per hectare Solaris cumulative	-Profit per hectare Solaris yearly	-Profit/loss -Solaris land allocation		
Net position cummulative	-Net position per year	-Yearly income to profit -Yearly expense removed from profit -Loans still owed		

Appendix E

Loskop Solaris Vensim Model – Additional assumptions

Table 23: Eskom average price increase and CPI from 1997-2011- taken from (Eskom, 2013)

Year	Average Eskom Tariff price adjustment %	CPI %
01-Jan-97	5	8.62
01-Jan-98	5	6.87
01-Jan-99	4.5	5.21
01-Jan-00	5.5	5.37
01-Jan-01	5.2	5.7
01-Jan-02	6.2	9.2
01-Jan-03	8.43	5.8
01-Jan-04	2.5	1.4
01-Jan-05	4.1	3.42
01-Apr-06	5.1	4.6
01-Apr-07	5.9	5.2
01-Apr-08	27.5	10.3
01-Jul-09	31.3	6.16
01-Apr-10	24.8	5.4
01-Apr-11	25.8	4.5
Average	**11.122**	**5.85**

Local authority rates - Ruraflex

Active energy charge [c/kWh]											
High demand season [Jun - Aug]						Low demand season [Sep - May]					
Peak		Standard		Off Peak		Peak		Standard		Off Peak	
	VAT incl		VAT incl		VAT incl		VAT incl		VAT incl		VAT incl
216.84	247.20	**65.69**	74.89	**35.67**	40.66	**70.74**	80.64	**48.69**	55.51	**30.88**	35.20
214.69	244.75	**65.04**	74.15	**35.31**	40.25	**70.04**	79.85	**48.19**	54.94	**30.57**	34.85

Figure 62: Eskom's current rural season tariff structure – copied from (Eskom, 2013)