Agriculture sector implications of a green economy transition in the Western Cape Province of South Africa: A system dynamics modelling approach to food crop production

by

Jacobus Bosman Smit van Niekerk

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

Department of Industrial Engineering,
University of Stellenbosch,
Private Bag X1, Matieland 7602, South Africa.

Supervisor: Prof. A.C. Brent
Co-supervisor: Dr. J.K. Musango

December 2015

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: ....
J.B.S. van Niekerk

Date: 2015/08/01

Abstract

Agriculture sector implications of a green economy transition in the Western Cape Province of South Africa: A system dynamics modelling approach to food crop production

J.B.S. van Niekerk

Department of Industrial Engineering,
University of Stellenbosch,
Private Bag X1, Matieland 7602, South Africa.

Thesis: MEng (Engineering Management)

September 2015

The Western Cape Province of South Africa has introduced a green economy plan called "Green is Smart". This initiative has the envisaged possibility of providing the Province with a sustainable economy. The transition towards a green economy will, however, have implications on the food crop production in the Province. Agriculture is a vital part of the Province's economy and a "systems thinking" approach is required to better understand how this transition will influence food crop production. The aim of this study is then to better understand systems thinking, identify different system modelling approaches, and to better understand how the Western Cape's agriculture acts as a complex system. By achieving this, the green economy transition can be better managed within the Province's food crop production.

After reviewing the literature, system dynamics modelling was identified as the preferred modelling technique to better understand the implications of a green economy transition of the Western Cape's food crop production. The model simulates the production for ten different food crops from 2001 until 2040. Food crops are produced with a combination of different framing practices, namely conventional, organic and conservation farming. There are three different green economy scenarios (pessimistic, realistic and optimistic), and one scenario where current practices are continued (business as usual).

The model results indicate that all three green economy scenarios will require significant financial investment. The results also indicate that only the optimistic green scenario might be worth the financial investment when considering the potential benefits. The study further provides recommendations for stakeholders in order to help this transition to a green economy within the Western Cape food crop sector. The study highlights the usefulness of using system dynamics to model and better comprehend complex systems. The limitations of system dynamics modelling are also discussed in this study. Difficulties with obtaining historical data and modelling sporadic events are the two most noteworthy limitations.

Uittreksel

Die gevolge van 'n oorgangsproses na 'n groen ekonomie vir landbou in die Wes-Kaap: Vanuit 'n stelsel dinamika model oogpunt gemik op voedselgewas produksie

("Agriculture sector implications of a green economy transition in the Western Cape Province of South Africa: A system dynamics modelling approach to food crop production")

J.B.S. van Niekerk

Departement Bedryfs Ingenieurswese,
Universiteit van Stellenbosch,
Privaatsak X1, Matieland 7602, Suid Afrika.

Tesis: MIng (Ingenieursbestuur)

September 2015

In Suid Afrika word daar tans 'n groen ekonomie raamwerk, naamlik "*Green is Smart*", voorgestel vir die Provinsie van die Wes-Kaap. Met hierdie raamwerk beoog die Provinsie om sy ekonomie in 'n meer lewensvatbare ekonomie te omskep. Die oorgangsproses na hierdie groen ekonomie gaan wel produksie van voedselgewasse in die Provinsie beïnvloed. Landbou speel 'n kern rol in die Provinsie se ekonomie, en 'n benadering wat die hele stelsel beskryf word daarom benodig om die invloed van hierdie oorgangsproses ten volle te begryp. Die doelwit van hierdie navorsings studie is dan om stelsel denkwyse, verskillende stelsel modellering tegnieke, en hoe die Wes-Kaapse landou sektor optree as 'n ingewikkelde sisteem, raadsaam te begryp. Deur hierdie ten volle te begryp, kan die oorgangsproses na 'n groen ekonomie volkome bestuur word ten opsigte van voedselgewas produksie in die Provinsie.

Nadat die literatuur nageslaan was, is daarop besluit dat stelsel dinamika modellering die gekose manier is om die gevolge van die oorgangsfase in voedselgewas produksie in die Wes-Kaap mee te modelleer. Altesaam is daar tien verskillende voedselgewasse se produksie wat gesimuleer word vanaf 2001 tot 2040. In die model is daar menige produksie kombinasie waarmee voedselgewasse geproduseer word naamlik konvensionele -, organiese - en bewarings produksie. Die studie ondersoek drie verskillende groen ekonomie gevalle (waarvan een 'n negatiewe -, verwagte - en positiewe uitkyk het) en een geval waar die ekonomie voortgaan met huidige beginsels en tegnieke van produksie.

Bevindinge van die model resultate let daarop dat 'n noemenswaardige kapitaalbelegging benodig word om enige van die drie organiese gevalle te bewerkstellig. Die resultate dui ook daarop dat die optimisties groen ekonomie geval al geval is wat as die moeite werd beskou kan word, wanneer die moontlike voordele met die kapitaal insette vergelyk word. Die navorsings studie verskaf ook draad aan aandeelhouers en ander partye oor hoe om hierdie oorgangsproses beter te bestuur. Verder word daar ook klem gelê op die nuttigheid van stelsel dinamika modellering vir soortgelyke navorsings probleme. Die beperkinge van stelsel dinamika modellering word ook onder die lesers se aandag gebring. Twee van die noemenswaardigste beperkings is om historiese data te verkry, en die feit dat dit moeilik is om ongereelde gebeurtenisse te simuleer met stelsel dinamika modellering.

Acknowledgements

I would like to express my sincere gratitude to Prof. A.C. Brent, my supervisor, for his guidance and support over the past two years.

I would also like to thank my co-supervisor, Dr. J.K. Musango, for her assistance while building the model.

To the National Research Foundation, thank you for partly funding this research. It was greatly appreciated.

A special thanks to my father for funding the rest of my research, and to my mother for her unwavering support.

To the rest of my family I would just like to say thank you for your unconditional love and support.

I would also like to thank my friends and colleagues, for their patience and motivation. I really appreciate everyone's jokes and amazing sense of humour.

To God, thank you for giving me daily strength and motivation.

Dedications

Hierdie tesis word opgedra aan oupa Koos en oupa Martin. Hulle was nooit bang om hard te werk nie en dit motiveer my elke dag. Ek glo hulle sou trots gewees het.

Contents

Declaration	**i**
Abstract	**ii**
Uittreksel	**iv**
Acknowledgements	**vi**
Dedications	**vii**
Contents	**viii**
List of Figures	**xii**
List of Tables	**xv**
List of Acronyms	**xvi**
1 Introduction	**1**
1.1 Background	1
1.2 Problem statement	3
1.3 The research objectives	3
1.4 Research outline	4
1.5 Conclusion: Background	4
2 Theory and Literature Analysis	**6**
2.1 Methodology	6
2.2 Systems thinking	8
2.3 Complex Systems Theory	10
2.4 Sustainable Transitions	12
2.5 An overview of Western Cape's agricultural food crop production	13
2.5.1 The Province's food crop production overview	13
2.5.2 Agriculture's environmental impact in the Province	15
2.5.3 Agriculture's economic impact in the Province	15
2.5.4 Agriculture's social impact in the Province	16

2.6 Understanding and analysing complex systems 17
2.6.1 Network Models 17
2.6.2 Discrete Event Simulation 19
2.6.3 System Dynamics Modelling 20
2.6.4 Agent-Based Modelling 22
2.6.5 Modelling approach conclusion 25
2.7 Conclusion: Theory and literature analysis 26

3 Modelling Methodology 27
3.1 Modelling approach analysis 27
3.1.1 Approach 1: Systems thinking and modelling process . . 27
3.1.2 Approach 2: Building a System Dynamics Model 29
3.1.3 Modelling approach conclusion 29
3.2 Problem structuring 30
3.2.1 Problem areas 31
3.2.2 Model boundary and time horizon 32
3.2.3 Preliminary information and data 32
3.3 Causal loop modelling 33
3.3.1 Population and food demand CLD 34
3.3.2 Food crop production CLD 34
3.3.3 Alternative farming options CLD 36
3.3.4 Food crop yield CLD 38
3.3.5 Environment impact CLD 38
3.3.6 GPD impact CLD 40
3.4 Dynamic modelling 41
3.4.1 Software used and simulation settings 41
3.4.2 CLD elements in the different stock and flow modules . . 42
3.4.3 Population module 42
3.4.4 Agricultural yield module 42
3.4.5 Food crop production module 44
3.4.6 Food crop price module 45
3.4.7 Emissions module 46
3.4.8 Green economy investment module 47
3.4.9 Other modules used 47
3.5 Testing 48
3.5.1 Guideline tests 49
3.5.2 Extreme-condition test 49
3.5.3 Sensitivity analysis 50
3.5.4 Historical data tests 51
3.5.5 Validation summary 53
3.6 Scenario planning and modelling 55
3.6.1 Scenario 1: Business as Usual 55
3.6.2 Scenario 2: Green Economy Worst Case 55
3.6.3 Scenario 3: Green Economy Realistic Case 56

3.6.4 Scenario 4: Green Economy Best Case 56
3.7 Conclusion: Modelling approach 56

4 Modelling Results 57
4.1 Model scenarios input parameters 57
4.2 Population 58
4.3 Yield per hectare 59
4.4 Food production 62
4.5 Land required 63
4.6 Food price 66
4.7 Emissions from food crop production 67
4.8 Green economy investment 69
4.9 Conclusion: Modelling outcomes 70

5 Study Conclusions and Recommendations 72
5.1 Important findings 72
5.1.1 Business as usual findings 73
5.1.2 Green economy worst case findings 73
5.1.3 Green economy realistic case findings 74
5.1.4 Green economy best case findings 74
5.2 Recommendations to stakeholders 74
5.2.1 Recommendation 1: Financial cost 75
5.2.2 Recommendation 2: Organic yield improvements 76
5.2.3 Recommendation 3: Conservation farming promotion . . 76
5.3 Model limitations 77
5.4 Suggested future research 78
5.5 Research reflection 79
5.5.1 Usefulness of SDM 80
5.5.2 Noteworthy findings 81
5.6 Concluding remarks 82

List of References 83

Appendices 90

A Stock and flow diagram modules 91

B Model validation 105
B.1 Sensitivity analysis test 1 105
B.2 Sensitivity analysis test 2 107

C Simulated results for yield for each of the 10 different food crop commodities 109

D Simulated production results for each of the 10 different food crop commodities **115**

E Simulated results for production area used for each of the 10 different food crop commodities **121**

F Simulated price results for each of the 10 different food crop commodities **127**

List of Figures

2.1 The literature review process for traditional approach(Cronin *et al.*, 2008). . . . 7
2.2 A system's structure. . . . 10
2.3 The interconnectedness of agriculture's different roles and functions (IAASTD, 2009). . . . 11
2.4 The six district areas of the Western Cape (Brown, 2014). . . . 14
2.5 A NM of the relationships between government, non-governmental organisations, universities, etc. (Davies, 2006). . . . 18
2.6 A DES model of an automated wet-etching station (Castro *et al.*, 2011). . . . 20
2.7 An SD model of predator prey (Borshchev and Filippov, 2004). . . . 21
2.8 An agent-based model that simulates a dynamic social network (Macal *et al.*, 2007). . . . 23

3.1 Phases of system thinking and modelling methodology (Maani and Cavana, 2012). . . . 28
3.2 Steps of building a systems dynamics model by Albin (1997). . . . 29
3.3 Adapted Approach 1 for SD model building. . . . 30
3.4 Basic population CLD (Maani and Cavana, 2012). . . . 34
3.5 Expanded CLD for food crop production. . . . 35
3.6 Population and food demand CLD. . . . 36
3.7 Food crop production CLD. . . . 37
3.8 Farming options CLD. . . . 37
3.9 Food crop yield CLD. . . . 39
3.10 Environmental impact CLD. . . . 39
3.11 GDP impact CLD. . . . 41
3.12 Annual onion production for Western Cape ($\sqrt{R} = 0.765$). . . . 52
3.13 Pear price for each year ($\sqrt{R} = 0.956$). . . . 52
3.14 Annual area used for wheat production in the Western Cape ($\sqrt{R} = 0.446$). . . . 53

4.1 The estimated Western Cape population size. . . . 59
4.2 The projected onion yield for the Western Cape. . . . 61
4.3 Total food crop production projected for the Western Cape. . . . 63

4.4 Total land requirements for the Western Cape's food crop production sector. . . . 64
4.5 The food price for citrus fruit with the four different scenarios. . . . 66
4.6 Annual GHG emissions created from total food crop production in the Western Cape. . . . 68
4.7 Accumulated investment required for each of the four different scenarios. . . . 69

A.1 The Western Cape population stock and flow module. . . . 92
A.2 Western Cape agriculture capital investment stock and flow module. 93
A.3 Western Cape water stress stock and flow module. . . . 94
A.4 Western Cape food demand stock and flow module. . . . 95
A.5 Western Cape planted area stock and flow module. . . . 96
A.6 Western Cape grain food crop production stock and flow module. . 97
A.7 Western Cape fruit food crop production stock and flow module. . . 98
A.8 Western Cape vegetable food crop production stock and flow module. 99
A.9 Grain price stock and flow module for wheat, canola, and barley. . . 100
A.10 Vegetable price stock and flow module for potatoes and onions. . . 101
A.11 Fruit price stock and flow module for apples, pears, citrus fruit, stone fruit, and wine and table grapes. . . . 102
A.12 The stock and flow module of food crop emissions, as a results of different production practices. . . . 103
A.13 The investment stock and flow module with different production practices. . . . 104

B.1 The sensitivity analysis for wheat price when grain price demand elasticity is changed. . . . 105
B.2 The sensitivity analysis for wheat production when grain price demand elasticity is changed. . . . 106
B.3 The sensitivity analysis for apple production emissions when initial fruit area required per type is changed. . . . 107
B.4 The sensitivity analysis for apples' annual agricultural investment when initial fruit area required per type is changed. . . . 108

C.1 Predicted wheat yield for the Western Cape. . . . 109
C.2 Predicted canola yield for the Western Cape. . . . 110
C.3 Predicted barley yield for the Western Cape. . . . 110
C.4 Predicted potato yield for the Western Cape. . . . 111
C.5 Predicted onion yield for the Western Cape. . . . 111
C.6 Predicted citrus fruit yield for the Western Cape. . . . 112
C.7 Predicted apple yield for the Western Cape. . . . 112
C.8 Predicted wine and table grapes yield for the Western Cape. . . . 113
C.9 Predicted stone fruit yield for the Western Cape. . . . 113
C.10 Predicted pear yield for the Western Cape. . . . 114

D.1 Predicted wheat production for the Western Cape ($\sqrt{R} = 0.0182$). . 115
D.2 Predicted canola production for the Western Cape ($\sqrt{R} = 0.162$). . 116
D.3 Predicted barley production for the Western Cape ($\sqrt{R} = 0.424$). . 116
D.4 Predicted potato production for the Western Cape ($\sqrt{R} = 0.385$). . 117
D.5 Predicted onion production for the Western Cape ($\sqrt{R} = 0.765$). . . 117
D.6 Predicted citrus production for the Western Cape ($\sqrt{R} = -0.241$). . 118
D.7 Predicted apple production for the Western Cape ($\sqrt{R} = -0.287$). . 118
D.8 Predicted wine and table grapes production for the Western Cape ($\sqrt{R} = 0.746$). 119
D.9 Predicted stone fruit production for the Western Cape ($\sqrt{R} = -0.666$). 119
D.10 Predicted pear production for the Western Cape ($\sqrt{R} = 0.290$). . . 120

E.1 Predicted wheat production area for the Western Cape ($\sqrt{R} = 0.446$).121
E.2 Predicted canola production area for the Western Cape ($\sqrt{R} = -0.209$). 122
E.3 Predicted barley production area for the Western Cape ($\sqrt{R} = -0.183$). 122
E.4 Predicted potato production area for the Western Cape ($\sqrt{R} = -0.771$). 123
E.5 Predicted onion production area for the Western Cape ($\sqrt{R} = 0.754$).123
E.6 Predicted citrus production area for the Western Cape ($\sqrt{R} = 0.119$).124
E.7 Predicted apple production area for the Western Cape ($\sqrt{R} = -0.401$). 124
E.8 Predicted wine and table grapes production area for the Western Cape ($\sqrt{R} = -2.18$). 125
E.9 Predicted stone fruit production area for the Western Cape ($\sqrt{R} = 0.157$). 125
E.10 Predicted pear production area for the Western Cape ($\sqrt{R} = -0.742$).126

F.1 Predicted wheat price for the Western Cape ($\sqrt{R} = 0.625$). 127
F.2 Predicted canola price for the Western Cape ($\sqrt{R} = 0.697$). 128
F.3 Predicted barley price for the Western Cape ($\sqrt{R} = 0.802$). 128
F.4 Predicted potato price for the Western Cape ($\sqrt{R} = 0.539$). 129
F.5 Predicted onion price for the Western Cape ($\sqrt{R} = 0.614$). 129
F.6 Predicted citrus price for the Western Cape ($\sqrt{R} = 0.562$). 130
F.7 Predicted apple price for the Western Cape ($\sqrt{R} = 0.917$). 130
F.8 Predicted wine and table grapes price for the Western Cape ($\sqrt{R} = 0.3759$). 131
F.9 Predicted stone fruit price for the Western Cape ($\sqrt{R} = 0.819$). . . 131
F.10 Predicted pear price for the Western Cape ($\sqrt{R} = 0.960$). 132

List of Tables

1.1 The outline of the study. 4

2.1 Example of different key words used. 8
2.2 Summary of the different modelling approaches (Balestrini-Robinson *et al.*, 2009). 25

3.1 The ten different farming commodities modelled 32
3.2 Data sources used in model variables. 33
3.3 Simulation settings summary. 42
3.4 Elements of the CLD's in the different dynamic modules. 43
3.5 Model validation summary. 54

4.1 The four different model scenarios input parameters. 58
4.2 A summary of the scenarios' yields for the ten different farming commodities ($ton/hectare$). 60
4.3 A summary of the scenarios' price results for the different commodities ($Rand/ton$). 65
4.4 A summary of simulated scenario results by 2040. 71

List of Acronyms

ABM	Agent-Based Modelling
BAU	Business As Usual
CAS	Complex Adaptive System
CGA	Citrus Growers Association
CLD	Causal Loop Diagram
DES	Discrete Event Simulation
DOA	Department of Agriculture
GEBC	Green Economy Best Case
GERC	Green Economy Realistic Case
GEWC	Green Economy Worst Case
GHG	Greenhouse Gas
KORKOM	Potatoes and Onions Committee
MLP	Multi-Level Perspective
NM	Network Models
SD	System Dynamics
SATGI	South African Table Grapes Industry
SAWIS	South African Wine Information & System
SDM	System Dynamics Modelling
SFD	System and Flow Diagram
TIS	Technological Innovation Systems
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme

Chapter 1

Introduction

This chapter serves as an introduction to the study conducted. It provides the reader with the global environmental setting and problem statement. The research outline discussed in this chapter is followed in an attempt to solve the research objectives formulated for this study.

This chapter aims to provided the foundation for the rest of the research by describing the research problem. An understanding of the problem is necessary in order to identify any potential shortcomings in the literature currently available. Understanding the problem at hand is also crucial to model development and helps to determine the audience to whom the model would be of value.

1.1 Background

The 20th[1] century was a period of growth for the Earth's human population and socio-economic development beyond compare. During this period, environmental constraints to human activity were often not fully recognised. The world is now experiencing a growing number of unwelcome consequences as continuous economic expansion and resource misuse threatens the stability of natural systems.

As countries and individuals have gathered wealth, their impact on the natural environment has increased. In some cases these impacts on the environment have been mitigated by different policies at national level, but often the outcome has been to transfer environmentally destructive actions to relatively poorer countries. There are therefore imbalances in the wealth and distribution of resources between wealthy and poor countries, and it is of critical importance to address these issues both among and within countries.

South Africa has a large amount of natural resources including some of the world's most significant mineral deposits, such as coal and natural gas (Na-

[1]A chapter from a paper presented at the IAMOT 2015 conference in Cape Town by the author (van Niekerk *et al.*, 2015).

tional Planning Commission, 2013). The exploitation of minerals is an energy exhausting activity. South Africa's large coal deposits currently represent a relatively cheap and reliable source of energy. South Africa is the 42nd largest emitter of CO_2 per capita and is among a number of developing countries that are likely to face globally forced emissions restrictions in the near future (National Planning Commission, 2013).

South Africa has therefore taken key strides to construct and implement measures to adapt to and lessen climate change. These steps form part of the country's commitment to reduce its emissions below a baseline of 34% by 2020 and 42% by 2025 (Western Cape Government, 2013*b*). This commitment, however, presents challenges to the economy and will require the design of a more sustainable development path.

Urgent developmental challenges in terms of poverty, unemployment and inequality are facing South Africa. The country will need to find methods to disconnect the economy from the environment in order to break the relations between economic activity, environmental degradation and carbon-intensive energy consumption. Numerous communities have been left excluded from economic opportunities and benefits while the natural environment was being misused in a way that was unreasonable (National Planning Commission, 2013). South Africa, therefore, needs to find different means to use its environmental resources to support the county's economy while keeping the economy competitive and meeting the needs of society. As such sustainable development needs to address be economic, social and environmental concerns.

The Western Cape currently is South Africa's leading agricultural export region and it's aquaculture region has an estimated triple digit growth rate (Western Cape Government, 2013*a*). The Western Cape however is projected to be among the provinces worst hit by climate change. This only adds concern to a region that is already water-stressed. The agricultural sector is currently the Western Cape's largest employer and faces a particularly challenging future as the sustainability of crops is threatened by climate change (Western Cape Government, 2013*a*).

The concept of a green economy provides a response to numerous global crises, such as: the climate, food and economic crises. It provides an alternative to current methods and offers the assurance of growth while protecting the earth's ecosystem which in turn results in poverty relief. This approach results in green economy gaining large backing and funding worldwide (UNEP, 2013*c*). The United Nations Economic Commission for Europe (UNECE) and the United Nations Environment Programme (UNEP) defines green economy as "*an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*" (UNECE, 2008; UNEP, 2003). The UNECE further observes that a green economy can be seen as an approach to provide an enhanced quality of life through a robust economy that is bound within the ecological constraints of the planet (UNECE, 2008)

The transition from current economic policies and methods to a green economy, thus, offers potential economic, social and environmental benefits. The Western Cape Government has realised the potential benefits of a green economy and started an initiative called "Green is Smart" (Western Cape Government, 2013*a*). This is a green economy strategy framework that is aimed at optimising green economic opportunities and enhancing environmental performance in the Western Cape. The framework also aims to make the Western Cape the lowest carbon province and leading green economic hub of the African continent, through the following five drivers: smart living and working, smart mobility, smart eco-systems, smart agri-production and smart enterprise (Western Cape Government, 2013*a*). From an agricultural perspective; farming of the future will belong to those areas that adopt water efficiency, energy efficiency, low-carbon and low resource intensity input technologies and practices.

1.2 Problem statement

There currently is literature available about the impacts of green economy investments in selected sectors pertaining to the South African economy (UNEP, 2013*b*; Musango *et al.*, 2014). This report, however, only looked at the impacts of green economy investment in the food crop sector at a national level. There is currently no literature available about the potential impacts of green economy investment at a provincial level for the Western Cape's agricultural sector. This research will possibly be of great benefit to the Western Cape Government if the impacts of green economy investment is assessed for the Province's food crop production.

The concept of a green economy is built on the three pillars of sustainable development, namely economic, social and environmental - and its particular focus on inter-generational equity (UNEP, 2013*c*). The Western Cape's agricultural food crop production will, therefore, be subject to economic, social and environmental issues when transitioning to a green economy. This creates a complex system of different drivers and entities. In view of this a holistic systems approach is necessary to understand the impacts of climate change and green economy investment. The Western Cape's agricultural food crop production sector could be susceptible to sudden and dramatic changes in climate or infrastructure.

1.3 The research objectives

The objective of this study is to provide assistance to stakeholders and policy markers on how to better manage the green economy transition within the agricultural food crop production sector of the Western Cape. In so doing, the study seeks to provide a better understanding of the implications of investments to transition the food crop production sector. An appropriate modelling method also needs to be selected and implemented that helps to better understand this green economy transition.

1.4 Research outline

The research objective identified above is addressed in Chapters 2 to 5 of this study. Table 1.1 provides the outline of the research document. Chapter 1 provides a brief introduction to the problem at hand and identifies the value of the research by identifying a gap in the literature. Chapter 2 discusses the literature review methodology and literature analysis results. The chapter aims to provide an understanding of the system and how systems function. Identifying the most applicable modelling approach of the food crop production system also forms part of Chapter 2.

Chapter 3 explains the identified modelling methodology used to build a model that represents the food crop production system. This enables a functional and accurate model to be built.The chapter also discusses and describes the different models that interact to form the system as a whole. Chapter 4 discusses the results obtained from the different simulation runs. Chapter 5 provides recommendations with regards to green economy investments for stakeholders and policy makers while identifying model improvements and highlighting shortcomings.

Table 1.1: The outline of the study.

Chapter	Description
1	Introduction
2	Theory and Literature Analysis
3	Modelling Methodology
4	Modelling Results
5	Study Conclusion and Recommendations

1.5 Conclusion: Background

This chapter provided an introduction into the research problem and highlighted then need for the Western Cape to adopt a green economy in order to improve it's environmental, economic, and social well-being. The problem statement identifies the gap in literature relating to how a transition to a green economy would affect the Western Cape's food crop production. This research could have great significance to stakeholders and policy markers.

The next chapter discusses the literature methodology and literature analysis. Chapter 2 also provides insight into complex systems, sustainable transitions, and different modelling approaches. A preferred modelling approach is also selected in the following chapter.

Chapter 2

Theory and Literature Analysis

The previous chapter, Chapter 1, the research problem was introduced. Transitioning to a green economy affects the Western Cape on environmental, economic, and social aspects. This results in the green economy affecting and interacting with a system that consists of multiple entities and role-players. Any change in the system could potentially have an impact on role-players or entities that aren't apparently clear.

In order to better understand the problem, research needs to be done into different theories and opinions. However, before this literature study or review can be executed, a research approach or method needs to be defined for this study. This section discusses the method used to obtain relevant literature.

In order to better understand how complex systems work and react to this green economy transition, from an agricultural perspective, literature is reviewed and analysed. The following theories are described in further depth in this chapter: systems thinking, complex system theory, sustainable transitions. An overview of the Western Cape's agricultural food crop production section is also provided. Understanding and analysis of complex systems is also discussed in order to identify the most appropriate modelling method. Understanding each of these theories provides a strong foundation for model building and simulation.

2.1 Methodology

There are many different types of literature reviews but the more popular ones are: traditional or narrative literature review, systematic literature review, meta-analysis, and meta-synthesis (Cronin *et al.*, 2008) . Traditional or narrative literature reviews consist of a body of literature that is reviewed and critiqued. This body of literature comprises relevant studies and knowledge about a subject region. Literature regarding a specific subject region is summarised and synthesised. This then provides the reader with a broad understanding of current knowledge and illustrates the importance of new re-

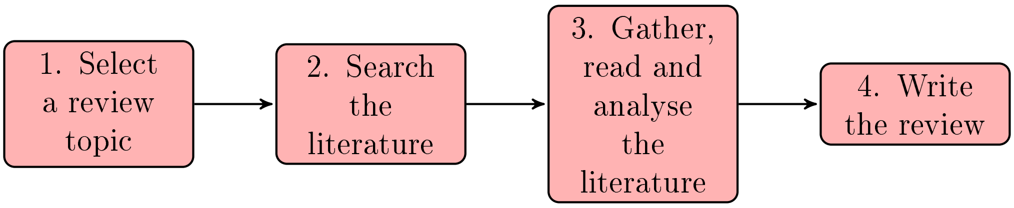

Figure 2.1: The literature review process for traditional approach(Cronin *et al.*, 2008).

search.

Since one of the objectives of this chapter is to better understand how the agriculture sector works as a system, this traditional literature review approach is followed. This will then provide a better understanding of concepts such as: systems thinking, complex systems, transition theory, and how this all forms part of the whole food crop agriculture sector.

Figure 2.1 illustrates the method for a traditional literature review. There are four steps in total (Cronin *et al.*, 2008). The first is step is to 'select a review topic'. The topic is the title of this study and the following steps will use this as a guide through the review process.

The second step is to 'search the literature' regarding the review topic. Today computers and electronic databases are mostly used since they are readily available and grant access to a vast amount of literature. SUNScholar and Google Scholar are the two main electronic databases that are used for this chapter. Since the topic is broad, many different keywords are use when searching for relevant literature in these electronic databases. Examples of the keywords used for reviewing literature is showed in Table 2.1. Journals are considered to be more up-to-date than books and are therefore preferred. The timeline for the search in the databases is kept from the year 2000 till present in order to keep theories and concepts "state of the art". Only fundamentally important theories dating beyond the 2000's are considered.

The third step is known as 'gather, read and analyse the literature'. In this step the literature is gathered by collecting the results from the keyword searches in the two electronic databases (SUNScholar and Google Scholar). Only the abstracts of the various articles are read to gain an understanding of their contents. If an article is identified as possibly containing knowledge that is important and can help to gain a better understanding into the topic under study, it is then classified into one of the four source types (primary source, secondary source, conceptual/theoretical, and anecdotal/opinion/clinical) (Cronin *et al.*, 2008) and skimmed through. During this "skimming" process all relevant theories, concepts and ideas are highlighted and marked for later use. Once the skimming process is completed, similar theories and concepts are linked, evaluated and critiqued.

The last step involves writing the literature review and can be found in

Table 2.1: Example of different key words used.

Topic segments	Keywords used in electronic databases
Agriculture	Food crops, Western Cape agriculture, Western Cape food crops, Agriculture as a system, Green agriculture, Wheat, etc.
Green economy	Green economy, Transition theory, Transition to a green economy, Sustainable economy, Western Cape green economy, Global green economy, etc.
Systems	Complex systems, Systems thinking, Systems, Agricultural systems, System dynamics, Understanding systems, etc.
Modelling	System models, How to model systems, Complex system models, Modelling techniques, System dynamics modelling, Network models, Discrete event simulation, Agent-based models, etc.

section 2.2 to section 2.6. During this step, the different views in the literature are discussed and combined to form a "bigger picture" of the research region or domain. Different concepts and theories are also discussed and critiqued.

2.2 Systems thinking

Jackson (2003) provides a definition for a system. He states that a system is a *whole* that consist of entities and depends on the interactions between these various entities. Maani and Cavana (2012) share Jackson's view by defining a system as *"something that is a collection of other things that form a group or entity"*. Jackson (2003) further explains that there are different types of systems such as: physical, natural, designed, abstract, social, and human activity systems.

There are two methods used to study systems, namely reductionism and holism. Østreng (2005) describes reductionism as the assumption that the behaviour of a system can be understood by examining the properties of its parts. Systems are broken down into their comprising entities and each entity is then examined individually. When the behaviour of the entities is understood, that of the whole system can be determined. Jackson (2003) however notes that it often becomes difficult to recognise the *whole* from its constituent parts.

Holism differs from reductionism in that the association among the entities and the system is thought to be more *symmetric* than in reductionism (Østreng, 2005). According to both Østreng (2005) and Jackson (2003), holism regards a systems to be more than the *"sum of their parts"*. The characteristics of the entities contribute to the understanding of the system, but these characteristics can only be completely understood through the behaviour of the system (Østreng, 2005). This means that the behaviour of a given system cannot be completely understood by the characteristics of its entities alone.

Midgley (2006) notes that any system consists of three important elements, namely perspectives, boundaries and entangled systems. When studying a system, it is important to view the behaviour from different perspectives. Not only should the *big picture* be studied, but also the interconnections between entities as well (Midgley, 2006). The boundary defines and limits the process and entities that make up the system as a whole. Each system also consists of entangled systems. There are systems within systems, systems that overlap with other system, and systems tangled up within each other (Midgley, 2006).

Sweeney and Sterman (2000) state that in order to successfully explain systems thinking, one needs the capacity to:

- understand how the behaviour of a system comes forth from the interactions between its entities/parts over time;
- discover and symbolise feedback loops which illustrate the flow of material and information;
- recognise stock and flow interactions;
- identify delays and comprehend their impact on the system;
- detect non-linearities.

Maani and Cavana (2012) have a similar view to explain systems thinking and describe it using the following four thinking types:

- *forest thinking* - having the capabilities to see the *big picture* and understand how a system's parts interact and communicate with each other;
- *dynamic thinking* - understanding that things continuously change and the world is therefore not static;
- *operational thinking* - understanding how process and entities work and affect each other;
- *closed-loop thinking* - realising that cause and effect are non-linear and that the *effect* can potentially impact the *cause*.

After reviewing the literature, a working definition for a system can be formulated. For the purpose of this study, therefore, a system is defined as consisting of smaller subsystems (*entities*) that interact with and influence each other. These subsystems interact with each other in a non-uniform way and results in non-linearities. A system has various inputs that affect these subsystems. The subsystems interpret these inputs and transform them into system outputs. System outputs can, however, affect system inputs and can be seen as a type of feedback loop. Figure 2.2 illustrates a graphical representation of a system, whether it is a physical, natural, designed, abstract, social, or human activity system. A system also operates in a certain environment, e.g.

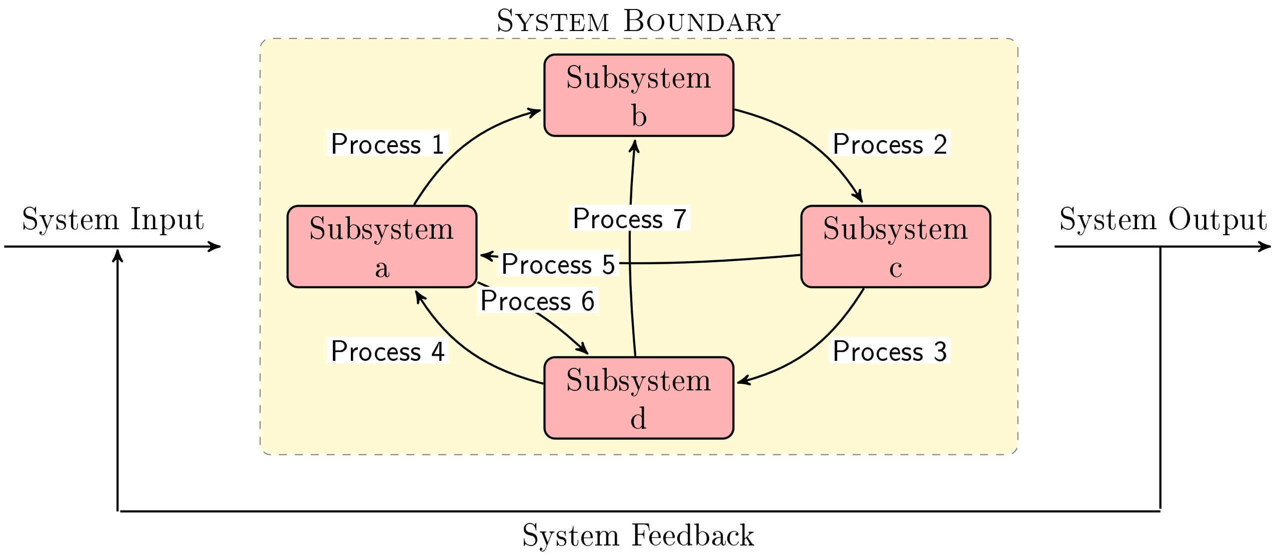

Figure 2.2: A system's structure.

the liver operates within the human body while an engine operates within a vehicle.

2.3 Complex Systems Theory

Systems[1] consist of multiple components and these components interact with each other to affect the whole system. Understanding how these components interact with each other and what drives these interactions is difficult. The literature describes agriculture as being a complex system, thus, an understanding of the *complex system theory* is important in the current study.

Wolfram (1985) describes the complex system theory as consisting of many components that are simple to understand and analyse. He, however, states that the problem for science arises when these components act together to produce behaviour of great complexity. Wolfram (1985) notes that it is of *crucial* importance to *formulate universal laws* that describe the system and its complexity, if it is possible. Rihani (2002) describes a system as being complex when "*their behaviour is defined to a large extent by local interactions between their components*".

Rihani (2002) further states that complex systems that are capable of evolution are known as *Complex Adaptive Systems* (CASs). There are three different *regimes* of behaviour for a CAS according to Rihani (2002). He defines these three regimes as: *order*, *chaos* and *self-organised complexity*. Rihani (2002) uses water in a bathtub as a simple example. He explains that when

[1] A chapter from a paper presented at the IAMOT 2015 conference in Cape Town by the author (van Niekerk *et al.*, 2015).

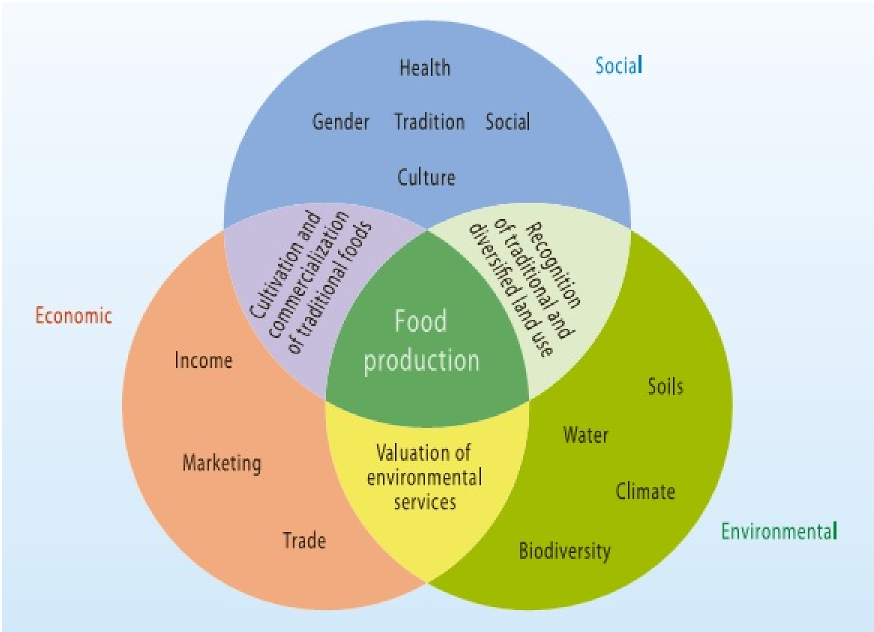

Figure 2.3: The interconnectedness of agriculture's different roles and functions (IAASTD, 2009).

the tap and plug are closed, the water is in order because its state hasn't changed. When the tap is opened fully, a state of chaos exists. When the water is running at a controlled rate and the plug is removed, self-organised complexity occurs. This last state is considered as self-organised complexity because, globally, there is an orderly pattern.

Rotmans and Loorbach (2009) note that CASs are special cases of complex systems. They share Rihani's view when they state that CASs have the ability to adapt and learn from previous experiences. Rihani simplifies his definition of CASs when he observes that such systems are able to adjust themselves and respond to fluctuations in their environment. Rotmans and Loorbach (2009) further state that what makes CASs different from other complex systems is the set of continuously altering non-linear relationships. CASs have components that interact with each other and adapt themselves to other components by altering conditions. CASs have distinctive characteristics among them, namely *co-evolution*, *emergence*, and *self-organisation* (Rotmans and Loorbach, 2009).

Co-evolution indicates the interaction between different systems that influences the dynamics of the individual systems. This results in patterns of alteration within each individual system (Rotmans and Loorbach, 2009). Emergence occurs during the process of self-organisation. During the emergence process, new structures, patterns and properties are created in the different systems. The process could also create characteristics at a higher level, but which cannot be understood at lower levels (Rotmans and Loorbach, 2009). Self-organisation refers to the ability for internal organisation systems to grow in complexity without external influences (Rotmans and Loorbach, 2009).

Figure 2.3 illustrates that agriculture operates within complex systems and is multi-functional in its nature (IAASTD, 2009). Green economy agriculture is focussed around the three pillars of sustainable development as can be seen in the three spheres. A multifunctional approach to implementing agricultural knowledge will enhance agriculture's impact on hunger and poverty. This collaboration of knowledge helps to improve quality of life in an environmentally, socially and economically sustainable manner (IAASTD, 2009). This multifunctional approach identifies the interconnectedness of agriculture's different roles and functions.

2.4 Sustainable Transitions

In[2] order to successfully transform the Western Cape's agricultural sector, the transition to a green and sustainable economy needs to be better understood. This section will look at some of the previous literature about sustainable transitions and help build a clearer understanding about the topic.

Major socio-economic challenges, as such natural resource depletion, global warming and decreased biodiversity, have resulted in the concept of socio-technical transitions (Kemp and van Lente, 2011). Transportation, energy and agricultural systems are out-dated in relation to the challenges the society currently faces, and, therefore, have to be modified and replaced (Kemp and van Lente, 2011). According to Geels (2011) these challenges can only be solved by societal awareness, and addressing the problems with intensified structural changes in transport-, energy supply-, and agricultural-food systems. Transitions to systems such as these are extremely complex and time consuming owing to the multiple roll-players throughout the transition (Geels, 2011). The socio-technical transitions require technological, political, economic and scientific knowledge. Thus, preserving or altering these systems requires the expertise of multiple role-players and industries such as policy makers, and politicians, consumers, civil societies, engineers and researchers.

Existing systems are usually stable and established, thus, changes and transitions in these systems are not easily performed. This applies to agricultural food systems according to Verbong and Geels (2010). The sunk investments in technologies, available expertise, and, social and ethical beliefs complicate the transition to a sustainable system. It is difficult to realistically assess visions and aspirations of sustainable agricultural systems. The problem often lies with the fact that the end product is visualised instead of attention being paid to the dynamic road or journey towards the end product (Verbong and Geels, 2010). Another problem is that too much emphasis is placed on the technologies used to modify and fix the systems, rather than focusing on the relevant

[2] A chapter from a paper presented at the IAMOT 2015 conference in Cape Town by the author (van Niekerk *et al.*, 2015).

social dynamics. Transitions directed at the vision of sustainability differ from transitions aimed at other purposes (Geels, 2011). Sustainable transitions have a main purpose of addressing environmental challenges. This leads to the changes in economic frame conditions, and lower price/performance benefits.

Socio-technical transitions are characterised by Coenen *et al.* (2012) as; (1) modifications and co-evolution, (2) multiple role-player collaborations between firms, consumers, scientific groups, politicians, social movements and special interest communities, (3) drastic changes in terms of the scope of the system, and (4) long term developments consisting of up to 40 to 50 year periods. The two foremost conceptual structures in innovative sustainability transition procedures are the Technological Innovation Systems (TIS) and the Multi-Level Perspective (MLP) (Coenen *et al.*, 2012). Both view socio-technical systems as semi-cohesive set of interconnected role-players, firms and technologies. The TIS method is concerned with new technological advances and their potential input towards sustainability. The MLP concept is focused on renovating historical procedures of regional change. MLP views transitions as a collaboration between drastic innovations, compulsory regime and an exterior landscape. The socio-technical transitions have three dimensions according to Verbong and Geels (2010) : (a) physical and technical elements, (b) a web of role-players and social groups, (c) formal and rational rules to direct the activities and role-players.

2.5 An overview of Western Cape's agricultural food crop production

The[3] Western Cape's food crop agriculture sector can be viewed as a CAS. It has all the elements of a system such as: various inputs, outputs, entities (subsystems), and process. It is considered to be complex because the various environmental, economic, and social entities interact with each other to form a system that is complex and able to adapt.

2.5.1 The Province's food crop production overview

The Western Cape can be divided into six districts, namely: Cape Peninsula, Cape Winelands, West Coast, Overberg, Central Karoo, and Garden Route and Klein Karoo (or Eden) districts. Figure 2.4 is a graphical illustration of the different districts within the Province. These six districts produce multiple agricultural products ranging from fruit, grain and livestock, to flowers.

There are up to 11 different commodities that significantly contribute to the Western Cape's agricultural accounting for more than 75% of total output

[3] A chapter adapted from a paper presented at the IAMOT 2015 conference in Cape Town by the author (van Niekerk *et al.*, 2015).

Figure 2.4: The six district areas of the Western Cape (Brown, 2014).

from the province according to Vink and Tregurtha (2005). These 11 different commodities include:

- fruit,
- winter grain,
- white meat,
- viticulture,
- vegetables,
- red meat,
- other animal products,
- dairy,
- eggs,
- animal fibre,
- and flowers.

The Cape Peninsula is mostly urban and therefore only has a small area available for agricultural practices. With regard to food crops, this area mostly produces vegetables and wine grapes. The Cape Winelands area is intensively cultivated and produces deciduous fruits, wine grapes, apples, pears, table grapes and onions (Vink and Tregurtha, 2005).

The West Coast region produces multiple food crops. The Swartland area is rain-fed and well know for producing wheat and canola. The Sandveld area uses irrigation to mostly grow potatoes. The northwest subregion of the West Coast mainly produces citrus and wine grapes (Vink and Tregurtha, 2005). The Overberg region also produces wheat, barley, and canola under rain-fed conditions.

Deciduous fruit are the main food crop commodity that is produced in the Klein Karoo area. Vegetables are produced in the Garden Route area under intensive irrigation. The Central Karoo's area is mostly used for grazing and rarely produces any food crops (Vink and Tregurtha, 2005).

2.5.2 Agriculture's environmental impact in the Province

Agriculture consists of more than just planting and harvesting crop for food. It has an impact within the local and global environment. Agriculture has the ability to change the local eco-system through the usage of fertiliser and pesticides. South Africa ranks 128 out of 132 countries with regard to environmental performance index according to a study done by Yale University (Western Cape Government, 2013*a*). This study measured air and water quality, biodiversity loss, and eco-system, agricultural and fishery system deterioration (Western Cape Government, 2013*a*). The global environment is also affected by agriculture. This is negatively affected primarily through CO2 emissions. The UNEP (2013*a*) states that agriculture contributes between 13% and 15% of greenhouse gas (GHG) emissions. The UNEP (2013*a*) further argues that the whole food system contributes to between 19% and 29% of GHG emissions.

2.5.3 Agriculture's economic impact in the Province

Agriculture in the Western Cape also has great economic importance. Food crops in the Western Cape can be categorised into three categories, namely: grains, fruit and vegetables. These three different categories contribute to 75% of the total output of its agricultural sector (Western Cape Department of Agriculture, 2005). Agriculture is also seen as one of the most important sectors of the Western Cape's economy. The Western Cape Province contributes 14% to South Africa's Gross Domestic Product (GDP) and the agriculture industry accounted for 5.2% of the Western Cape's Gross Regional Product in 2004 (R 185.40 billion) (SAinfo, 2012; Western Cape Department of Agriculture, 2005). The main food crop industries in the Western Cape include the following (Western Cape Department of Agriculture, 2005):

- fruit, which contributes R 2.4 billion;
- winter grain, which contributes R 1.8 billion;
- viticulture, which contributes R 1.6 billion;
- and vegetables, which contributes R 1.4 billion.

The area used for agriculture in the Western Cape spans 11.5 million hectares and accounts for 12.4% of the total land available in South Africa that is suitable for agriculture. The Western Cape's agriculture contributed to ± 20% of South Africa's total agricultural production in 2004, and accounted for between 55% and 60% of the country's agricultural exports (Western Cape Department of Agriculture, 2005).

Antle (2008) states that agriculture is the most important sector of any economy that is highly dependent on the climate and climate changes. Nelson *et al.* (2014) notes that the initial effect of climate change on agriculture is crop yield. This results in reduced production and increased prices. When this happens, Nelson *et al.* (2014) finds that the consumers will change their behaviour by reducing their consumption of more expensive food crops and replace them with other suitable substitutes. Farmers then react by changing management systems and improving yield per area. The Global Agriculture is also affected and this results in changes in multiple economies.

2.5.4 Agriculture's social impact in the Province

Agriculture has multiple social impacts. Hilchey *et al.* (2008) have identified a few positive impacts in past studies. They state that agriculture: 1) provides high quality and local food; 2) contributes to local food security and safety; 3) contributes to community and quality of societal life; and 4) preserves valuable heritage, traditions, and work ethic. Agri SA (2013), however, notes that there are negative social impacts as well. They refer to the labour unrest in the Western Cape at the end of 2012. This unrest resulted in strikes in approximately 16 municipal districts in the Province, property damage and concerns for farmer safety. Employees were displeased with their daily wage, living and working conditions. Employees demanded a wage increase, their demands were met, and resulted in an increase of 52% in minimum daily wage. This increase in wage demands however also had an economic impact. According to Agri SA (2013), this increase in minimum wage resulted in the following actions being taken by farmers:

- retrenchment of farm workers;
- changes in farming practices;
- participation in the "training lay-off scheme";
- and applying for exclusion from paying the new minimum wage.

Land reform in South Africa also affects agriculture in economic, environmental, and social aspects. The land reform policy being implemented in South Africa has the following beneficial impacts according to Hall (2009) :

- improved food security
- increased income
- increased well-being
- reduced vulnerability
- sustainability.

The current ruling political party, African National Congress (ANC), has proposed a new land reform bill where they relocate 50% of the property to employees. This 50% of the property will not be paid to the owner but will go into an investment and development fund (SAPA, 2014). In an interview with the Mail & Guardian newspaper, the Democratic Alliance (DA) leader, Helen Zille, argued that this new land reform bill would "*exacerbate insecurity, destroy jobs, escalate the already catastrophic exodus of farming expertise from the industry and have dire implications for food security in the medium term*" SAPA (2014). According to the Afrikaanse Handelsinstituut (AHi), the latest land reform bill will lead to disinvestment in agriculture and as a consequence, poses a serious risk to food security (Fin24, 2014).

2.6 Understanding and analysing complex systems

Models that are founded on non-linear interactions and relationships are difficult to solve analytically (Sonnessa, 2004). A mathematical computation based on iterative algorithms is the recommended method to solve these models according to Sonnessa (2004). Simulation is identified as the most appropriate method to analyse and understand complex systems. Simulation with models integrates the effect of "simple" processes over complex "spaces". Simulation also cumulates the effects of these same "simple" processes over time (Wainwright and Mulligan, 2013). Wainwright and Mulligan (2013) note that simulation allows for a system's behaviour to be predicted outside the time or space domain for which data is available. Four of the most generally used modelling and simulation methods according to Balestrini-Robinson *et al.* (2009) are discussed in this section, namely network models, discrete event simulation, system dynamic modelling and agent-based models. Each method is described and critiqued as applicable.

2.6.1 Network Models

Network models (NMs) are where nodes represent different system mechanisms and bind the physical and relational connections between the system's mechanisms (Ouyang, 2014). NMs can be used to model different systems according to Goldenberg *et al.* (2010). They state that NMs can either be used for statistical modelling or to analyse social, computer, physical and biological network models. Goldenberg *et al.* (2010) further note that NMs are either static or dynamic models. On the one hand, static NMs explain the observed "set of links" of a network in a snapshot of time (Goldenberg *et al.*, 2010). Dynamic NMs, on the other hand, focus on the mechanisms that govern the network and network changes over time (Goldenberg *et al.*, 2010). Goldenberg *et al.* (2010)

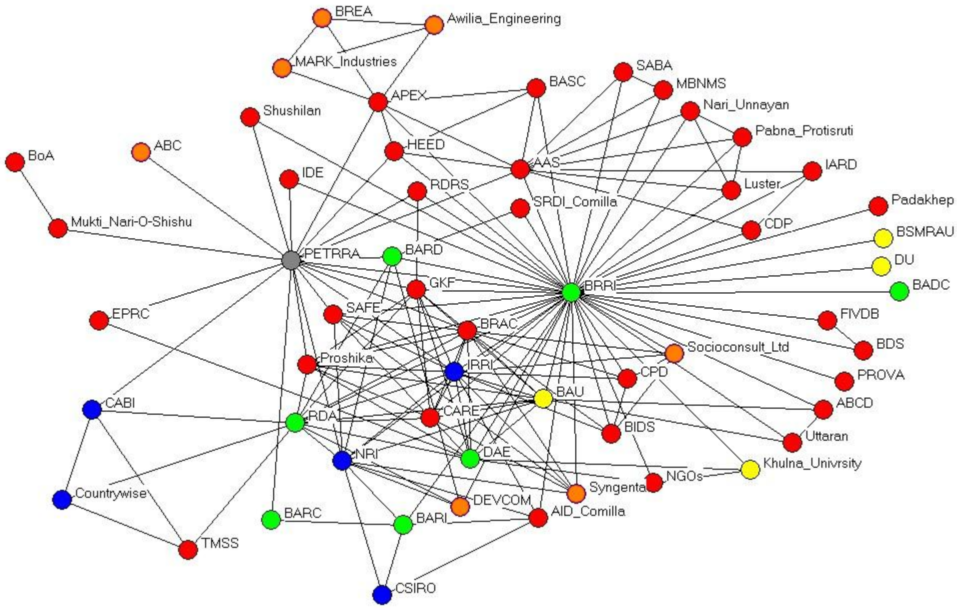

Figure 2.5: A NM of the relationships between government, non-governmental organisations, universities, etc. (Davies, 2006).

note that early NMs were mostly static, but as more data became available, interest started growing into using dynamic NMs.

NMs are ideal for both discrete and continuous optimisation for networks or systems according to Bertsekas (1998). Newman *et al.* (2002) observe that NMs have been ideal for social network analysis. They argue that social studies are appropriate for NMs owing to the fact that social networks can be broken down into three characteristic features, namely (1) entities interact with each other without necessarily being aware of the interaction; (2) entities form a *cluster* of interactions between each other; and (3) the distribution of interactions between entities are skewed. Gen *et al.* (2008) agrees with Bertsekas and states that NMs are ideal from optimisation problems such as:

- shortest path
- resources assignment
- transhipment
- multi-commodityflow
- and traveling salesman.

It is important to understand a network's *anatomy* because the network structure always has an affect on the network's function according to Strogatz (2001). The structure of social networks affects the spread of disease and information while the structure of a food production system affects its robustness and stability to provide.

This approach models single systems by networks and describes the interconnection by inter-links, which provide flow patterns and creates a system diagram. Figure 2.5 is an example of a network model that was used to contribute to the alleviation of poverty in Bangladesh with a research project called PETRRA. The research focused on increasing rice production for farmers who lacked farming resources. The green nodes represent government bodies, while red represent non-governmental organisations (NGO) and the yellow represent universities. This network model highlighted the importance of Government-NGO and University-NGO relationships, which only became clear as the project developed.

Balestrini-Robinson *et al.* (2009) explains that NMs use a number of algorithms to compute *characteristics* of graphs (e.g. flow graphs, bipartite graphs, etc.) that describe the system. These graphs can then be used to imitate the characteristics of real networks. Balestrini-Robinson *et al.* (2009) however critics NMs and states that they are only suitable to capture functional complexities in the network. The graphs do not capture space and time dependent effects in the network.

2.6.2 Discrete Event Simulation

Discrete event simulation (DES) is used to study systems by simulating their expected behaviour according to Jacob (2013). He describes DES as a computer program that mimics the system's behaviour. Jacob (2013) distinguishes between DES and other simulation types, by stating that simulation program *"keeps track of the state of the system as time progresses"*. He further describes this *state* as the condition of the system at any given time during the simulation. Jacob (2013) also notes that any changes in the system *state* occurs at a time instant, and these changes are referred to as *events*.

Babulak and Wang (2010) share a similar view to Jacob's and observe that DES *"quantitatively represents the real world, simulates its dynamics on an event-by-event basis, and generates detailed performance report"*. According to Albrecht (2010), DES *"utilises a mathematical/logical model of a physical system that portrays state changes at precise points in simulated time. Both the nature of the state change and the time at which the change occurs mandate precise description"*. Brailsford and Hilton (2001), in turn, describe DES as a system consisting of a network of activities and queues. They, however, agree with the previous statements about events occurring at discrete points in time. Brailsford and Hilton (2001) further state that objects of the system are distinct entities that possess their own properties, and that these properties determine what happens to each entity over time. Allen (2014) shares the above views with regard to DES being time dependent and states that DES is *"an approach based on the assumption that the state of the simulation changes at discrete-time intervals"*.

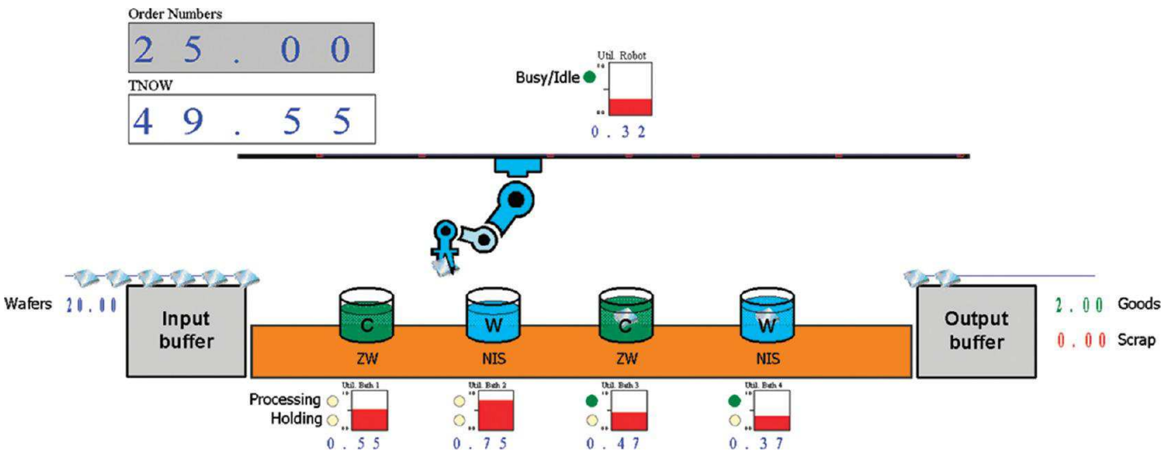

Figure 2.6: A DES model of an automated wet-etching station (Castro *et al.*, 2011).

Figure 2.6 represents the system of wafer lots that need to go through a series of chemical and water baths. One single robot moves the wafer lots through the whole process at discrete time intervals. An *event* in this model is when a wafer lot is moved while a change in the *state* would be when a wafer lot goes through one of the chemical or water baths.

DES can be applied to the manufacturing and service sector (Babulak and Wang, 2010). Babulak and Wang (2010) also identify "Business Intelligence Systems" and "Simulation-based Education" as new areas and opportunities to apply DES to. Balestrini-Robinson *et al.* (2009) note that DES is preferred by logistics companies to model supply chains. Diaz and Behr (2010) find that DES is an applicable approach in answering efficiency related questions. They also highlight that DES is better suited to answer questions with regard to entities flowing through queues and servers than other simulation techniques.

Balestrini-Robinson *et al.* (2009) critiques DES and states that any model that requires free movement of entities, or a very detailed movement pattern, is not easily simulated with DES. Maidstone (2012) argues that DES tends to only look at the smaller detail of a system. Maidstone (2012) further critiques DES by stating that DES is stochastic and will, therefore, give contrasting results on different runs. The model, thus, needs to be run multiple times in order to gain a better understanding of the system.

2.6.3 System Dynamics Modelling

System dynamics modelling (SDM) was originally developed by Jay Forrester at the Massachusetts Institute of Technology (MIT) for industrial problems. The application of SDM has recently changed from industrial problems to social, technological, environmental and agricultural systems (De Wit and Crookes, 2013). De Wit and Crookes (2013) define SDM as a simulation approach used to better understand complex problems and systems. Pejić-Bach and Čerić (2007) define SDM as the process *"analysing the structure and the behaviour of the system as well as for designing efficient policies of managing the system"*.

Tedeschi *et al.* (2011) view SDM as a modelling approach that *"applies systems thinking to develop models that are used to describe (and simulate) the interactions among variables, by clearly identifying the behaviour of the variable"*. Tedeschi *et al.* (2011) further describes SDM as a *conceptual tool* that can be used to understand the structure and dynamics of complex systems. Stave (2003) argues that SDM is a *"problem evaluation approach"* based on the understanding that the structure of a system generates its behaviour. He defines the structure of a system as the way in which system components are connected. Angerhofer and Angelides (2000) describe SDM as computer-aided method that can be used to examine and explain complex problems with an emphasis on policy analysis and design.

De Wit and Crookes (2013) argue that system models can either be quantitative or qualitative and that SDM is a quantitative approach. The SDM is defined by the dynamic behaviour and non-linear feedbacks of the system. This is as a result of the interwoven relationships and interactions between entities and variables in the system (De Wit and Crookes, 2013). De Wit and Crookes (2013) also note that in order to better comprehend system complexity, one needs to understand: (1) the systems as a unit and not just a part of the system, (2) a modelling approach that is able to take into account non-linearities in the interactions between the parameters, and (3) feedback loops and models that take into account stock variables as well as flow variables. Social systems contain numerous non-linear relationships according to Angerhofer and Angelides (2000), and result in an analytical or logical solution to solving model equations not being feasible.

SDM can help to better understand the structure and behaviour of systems

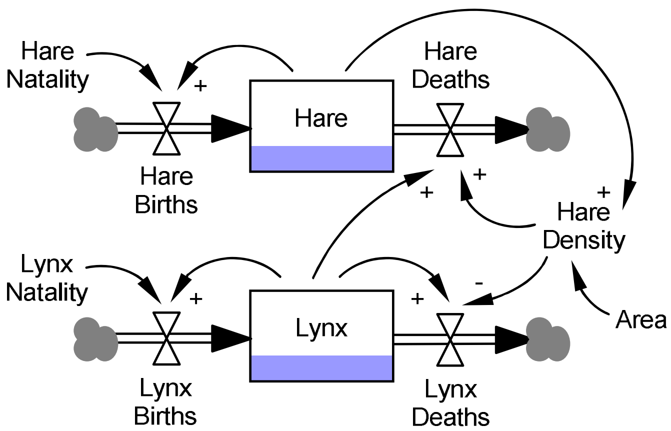

Figure 2.7: An SD model of predator prey (Borshchev and Filippov, 2004).

with non-linear links and feedback according to Pejić-Bach and Čerić (2007). Stave (2003) notes that SDM can assist managers to communicate with stakeholders. He argues that managers can use the information from the system to visually illustrate the results of different actions, without having to describe all the technical details of the system to the stakeholders.

The areas of application for SDM are numerous, but recently, it has been largely applied to socio-economic problems (Ahmad and Simonovic, 2000). Figure 2.7 is an example where SDM was used to model a predator and prey system, where lynxes hunt hares. According to Angerhofer and Angelides (2000), the other areas where SDM has been applied include:

- work in corporate planning and policy design
- economic behaviour
- public management and policy
- biological and medical modelling
- theory development in the natural and social sciences
- dynamic decision making
- energy and the environment
- software engineering
- complex non-linear dynamics
- and supply chain management.

Balestrini-Robinson *et al.* (2009) raise three concerns with regard to SDM: Firstly, she notes that it is difficult to determine the scope of the problem that should be modelled during model construction. Secondly, the modeller must understand the system and components from a multi-level perspective. Lastly, it is difficult to obtain accurate aggregated data.

Pejić-Bach and Čerić (2007) also critiques SDM and states that it is difficult to understand model behaviour if the development of the model is not incremental. Pejić-Bach and Čerić (2007), therefore, suggests that a *step-by-step* approach be followed during model development. This approach combines the evaluation of the model and the process of model development, which in turn, allows for better understanding of the model and increases confidence in it and its findings.

2.6.4 Agent-Based Modelling

Agent-based modelling (ABM) is an approach to model complex systems that consist of interacting and autonomous *agents* according to Macal and North (2010). They further explain that these agents have behaviour that are governed by simple rules and interactions with other agents, which then determine their behaviour. Janssen (2005) shares Macal and North's view and states that ABM *"is the computational study of social agents as evolving systems of*

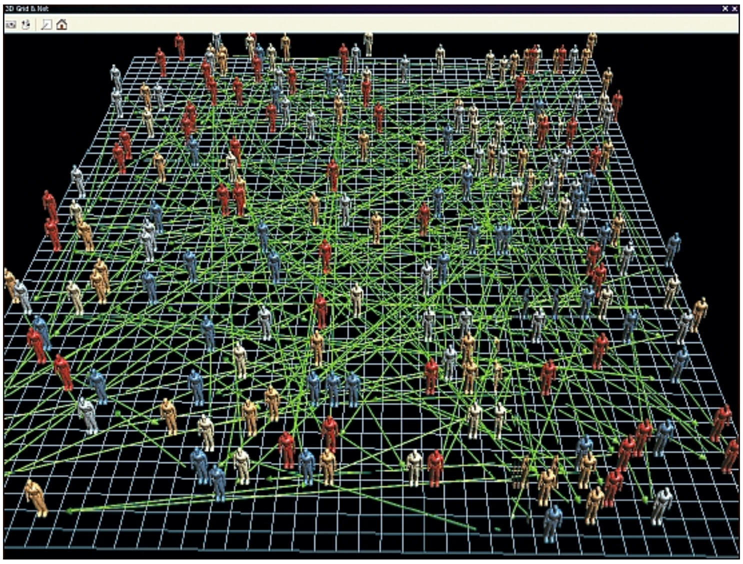

Figure 2.8: An agent-based model that simulates a dynamic social network (Macal *et al.*, 2007).

autonomous interacting agents". Farmer and Foley (2009) have a similar description of ABM and describe it as *"a computerised simulation of a number of decision-makers (agents) and institutions, which interact through prescribed rules"*.

Figure 2.8 illustrates an agent-based model that depicts a social network. There are multiple agents (human beings) that interact with each other. They affect other agents both directly and indirectly and this then gives behaviour to the system as a whole, which can change over time.

Janssen (2005) explains that for some problems, equation based models are sufficient to understand the problem at hand. He, however, argues that if the problem involves coordination or strategic interaction, then multiple agents need to be differentiated. Similarly, Macal and North (2010) argue that by modelling agents individually, the effect of their behaviour and characteristics on the system's behaviour as a unit can be observed. Holland (1992) has a similar view and states that ABM is used if the researcher is concerned with how macro phenomena emerges from micro level interactions and behaviour of different system agents. An ABM approach suggests that complex systems are formed from the bottom-up according to Crooks *et al.* (2008), which is similar to previous views and opinions. Macal and North (2010) further explain the characteristics of ABM and state that *"patterns, structures, and behaviours emerge that were not explicitly programmed into the model, but arise through the agent interactions"*.

Macal and North (2010) describe ABM as consisting of three elements, namely:

- the *agents*, and their attributes and behaviour.

- the *agent relationships*, and methods of how agents interact with each other.
- the *agents environment*, and how agents interact with their environment.

Wooldridge (2009) argues that agents, that are intelligent, are able to adapt and act independently. Agents also have seven characteristics of their own according to Macal and North (2010). Firstly, an agent is *self-contained and uniquely identifiable*, which means one can easily determine whether an attribute is part of an agent or shared. Secondly, agents are *autonomous and self-directed*, which results in agents functioning independently in their environment. Agents also have a *state* and this differs over time. An agent can also be *social* and, therefore, interact with other agents and influence their behaviour in the system. Agents could also have the ability to *adapt*, which means that they could learn from previous experiences. They could also be *goal-directed* and have objectives to achieve. Finally, agents can be *heterogeneous* and have different characteristics.

Abdou *et al.* (2012) in turn describes ABM agents as having four noteworthy properties, namely:

- *Perception*: agents can perceive their environment, which includes other interacting agents.
- *Performance*: agents have a set of activities that they are allowed to perform such as moving, communicating, and interacting.
- *Memory*: agents use their memory to record their previous states and actions.
- *Policy*: Agents have a set of rules or policies that determine what their future actions should be.

The application areas for ABM differ from modelling agent behaviour in the stock market to understanding consumer purchasing behaviour; from predicting the spread of epidemics to modelling the adaptive immune system Macal and North (2010). Farmer and Foley (2009) also note that ABM provides a potential solution to model the financial economy as a complex system.

Balestrini-Robinson *et al.* (2009) argues that there are multiple shortcomings of ABM. Firstly, she notes that it is difficult to determine which portions of reality should be modelled. The next issue that she identifies is that it is sometimes unclear which portions of the model can be characterised as independent events. The third issue is that every interaction at the individual levels may not be known or understood sufficiently. Balestrini-Robinson *et al.* (2009) critiques ABM further by stating that playing it safe and attempting to model as much as possible can create a model that is too complicated to execute efficiently. This can result in the understanding of the system being impaired. Finally, ABM needs to run a very large number of simulations seeing that the interactions reduce the effectiveness of the “Central Limit Theorem”.

Table 2.2: Summary of the different modelling approaches (Balestrini-Robinson *et al.*, 2009).

Attributes	Modelling Approaches			
	NM	*DES*	*SDM*	*ABM*
Ease of creation	Excellent	Very poor	Good	Very poor
Dynamic behaviour	Poor	Very good	Very good	Very good
Non-linearity	Very poor	Very good	Very good	Excellent
Interactions	Very good	Poor	Poor	Excellent
Ease of validation and verification	Very good	Good	Good	Very poor

2.6.5 Modelling approach conclusion

A single modelling approach needs to be identified that can be used to achieve the objectives of this research project. By reviewing the critique of the different models from Section 2.6.1 to 2.6.4, a modelling approach conclusion can be made. In addition, Table 2.2 describes the key attributes of each modelling approach as identified by Balestrini-Robinson *et al.* (2009). For this study, *ease of creation* and *non-linearity* are viewed as the most desired attributes from the list, since there is a time constraint to the research and there are non-linear interactions in the complex system of food crop production.

NM is deemed as an insufficient approach to modelling the agriculture sector implications of a green economy transition in the Western Cape Province. The argument is that NMs is more suitable to understand the relationship between system variables and how they associate with each other. It was also noted that NMs are not suitable to capture space and time dependent effects in a system. Table 2.2 also shows that NMs are very poor at incorporating non-linearities in the model.

DES is also rejected because it is better suited for modelling supply chains and queues. The approach also tends to focus on the finer details of the system rather that the system as a whole. The modelling approach is stochastic and, therefore, requires multiple model simulation runs, which is not ideal. Another shortfall of DES is that model creation is cumbersome as reflected in Table 2.2.

SDM and ABM are, therefore, considered the most appropriate modelling techniques to use to better understand the implications that a green economy transition will have on the Western Cape's food crop production. SDM and ABM share similar shortcomings such as difficulty to determine the scope of the system, and that the modeller needs to understand the system, its components and their different interactions.

For the purposes of this study, however, ABM is rejected owing to the fact that the model is constructed at an individual (micro) level. It is difficult to identify the individual entities for the food crop production system of the

Western Cape, and then determine their individual behaviour on a micro and macro level. From Table 2.2, it should be noted that ABM is excellent at incorporating *non-linearities* in the system, but it is heavily critiqued for its poor *ease of creation* and *ease of validation and verification*.

SDM is, therefore, chosen as the preferred modelling approach to better understand the impact this green economy transition will have on the Province's food crop production. Table 2.2 depicts SDM as being the best all-round modelling approach, with its only weakness being *interactions* between model entities and variables. The problem will be easier to model from system dynamics point of view, since the economy consists of a multitude of role-players and entities. A macro level approach is, therefore, best suited to understand the problem at hand when the problem becomes too complex from a micro level perspective. SDM will also provide a more holistic solution to where green investments should be made with the food crop production sector.

2.7 Conclusion: Theory and literature analysis

The theory and literature analysis chapter supported the study by defining a method to conduct a literature analysis. In order to better understand how the food crop production system of the Western Cape functions literature regarding systems thinking, complex systems, and sustainable transitions were discussed in this chapter. The Western Cape was also described in terms of food crop production and the social, environmental, and economic impacts agriculture has in the Province. Four different modelling methods that would help to better understand complex systems were discussed and compared. System dynamics modelling is chosen as the preferred method to model the implications of a green economy transition within the Western Cape food crop production.

The next chapter identifies two modelling approaches or methodologies that can be applied to build a SD model. After an appropriate modelling approach is selected, the steps of the approach are applied to build a food crop production model. The model is also validated in the chapter and scenarios are defined.

Chapter 3

Modelling Methodology

In the previous chapter system dynamics modelling (SDM) was identified as the most appropriate modelling method to investigate the impact of a green economy transition on the Western Cape's food crop production. In order to build a functioning systems dynamics (SD) model, a modelling methodology or approach needs to be defined.

For the SD model to be functional and accurate, the right building method must be identified and followed. This helps to build confidence in the model and its simulated results. The model's results are subsequently used to advise stakeholders, highlighting the importance of having confidence in the model findings.

This chapter briefly describes two different SDM methods and their modelling phases, a preferred method is subsequently selected. After the preferred method is selected, the modelling phases are systematically followed and described to successfully build a systems dynamics model for the Western Cape's food crop production.

3.1 Modelling approach analysis

As previously mentioned, this chapter discusses two approaches to building a system dynamics model. Both Maani and Cavana (2012) and Albin (1997) describe two different yet overlapping methods to build a functioning system dynamics model. These two approaches are evaluated and the limitations of each approach are discussed in this section. The selected approach is then used as a guideline to build the system dynamics model for this study.

3.1.1 Approach 1: Systems thinking and modelling process

The first approach that was evaluated for constructing a system dynamics model is described by Maani and Cavana (2012). They note that this process

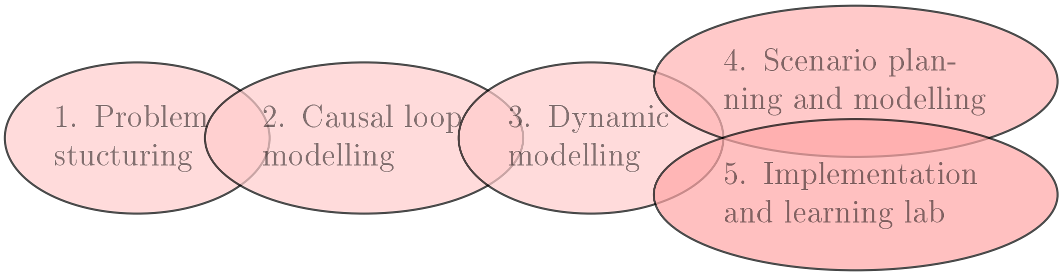

Figure 3.1: Phases of system thinking and modelling methodology (Maani and Cavana, 2012).

consists of five different phases. Figure 3.1 illustrates the five phases of their approach for building a systems dynamics model. Within each phase a set of steps are defined; these steps explain the process at a more detailed level. Each of the five phases and their underlining steps are described by Maani and Cavana (2012) as follows:

The *problem structuring* phase consists of identifying the problem area or policy issues that concerns stakeholders. These steps require that the objectives of research are clearly identified and that multiple perspectives be taken into account. Collecting preliminary information and data as well as group session discussions are also steps that form part of this phase.

The first steps in the *causal loop modelling* phase requires the model developer to identify the main variables and draw the behaviour of these variables over time. Causal loop diagrams (CLDs) are subsequently developed to illustrate the relationship between the different variables. If possible, the different system archetypes are also identified during this phase. The causal loop modelling phase improves the conceptualisation of the system and its behaviour.

The *dynamic modelling* phase builds on the causal loop modelling phase. This phase involves the actual model building process. Variable types are defined (e.g. stocks, flows, etc.) during this process. The simulation model is then built based on the CLDs that are used to construct stock and flow diagrams (SFDs). The model is validated and, subsequently, a sensitivity analysis is recommended to determine the model's sensitivity to parameters and initial values.

During the *scenario planning and modelling* phase various scenarios and policies are developed and tested. Key drivers of changes are identified in this process. Scenarios are a combination of policies or events. Pessimistic and optimistic scenarios can also be run and evaluated where scenarios only have negative of positive outcomes.

The last phase, *implementation and learning lab*, is where the developed models are improved by expanding them into a microworld. Microworlds are tools that can be used by stakeholders and managers to experiment with the model themselves. This acts as a learning laboratory for both model developers

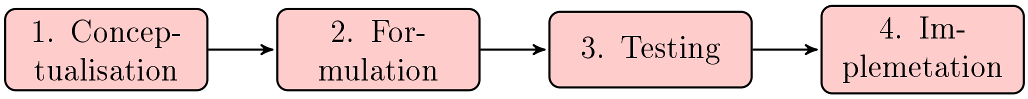

Figure 3.2: Steps of building a systems dynamics model by Albin (1997).

(since they can receive feedback from stakeholders) and stakeholders (since they can observe the simulated results of their experiments).

3.1.2 Approach 2: Building a System Dynamics Model

The second approach that was evaluated that can be used to build a system dynamics model is described by Albin (1997). She states that the approach consists of four phases, namely conceptualisation, formulation, testing and implementation. Figure 3.2 shows these four phases. As with the previous method, each of the these phases has underlining steps as described by Albin (1997).

In the first phase, which is called the *conceptualisation* phase, the purpose of the model is defined. Additionally, the model boundary is determined and the key variables are defined for the system. The model audience should also be identified for this phases. Reference modes are drawn that describe the different variables' behaviour, which is similar to the first approach. In the last step of this phase, feedback loops (or CLDs) for the system need to be constructed in order to better understand system behaviour.

During the *formulation* phase, the first step is to convert the feedback loops from the conceptualisation phase into rate equations. System parameters are also approximated during this phase. After these two steps have been completed, the simulation model is constructed, which is considered to be the last step.

The third phase, *testing*, involves the actual simulation of the model. The model is tested and model assumptions are evaluated in the second step of this phase. This second step requires that the model behaviour is tested and that a sensitivity analysis is undertaken.

During the final phase, the *implementation* phase, the model's response to different policies and scenarios is tested. The results of these policy and scenario tests are then used to make recommendations to stakeholders. Stakeholders can use these recommendations to evaluate and invest in different solutions for the modelled policies and scenarios.

3.1.3 Modelling approach conclusion

Approaches 1 and 2 are similar approaches that can be used to build a systems dynamics model. In terms of stakeholder engagement, the two approaches that were described follow different philosophies. In Approach 1, the philosophy is

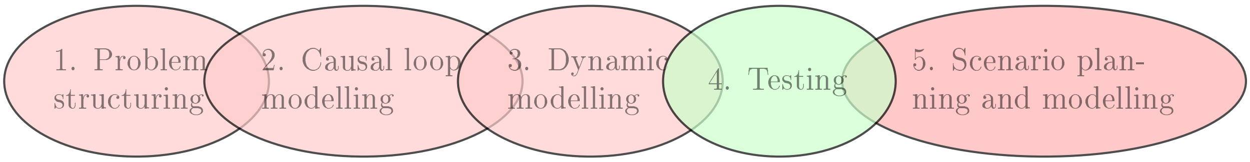

Figure 3.3: Adapted Approach 1 for SD model building.

to consult with stakeholders during the first phase. This is an advantage if stakeholders approach the model developer with an identified problem that needs to be solved or improved. The drawback of this philosophy is that if a problem is identified without the aid of stakeholders, or if it is unclear who the associated stakeholders are with regard to the problem, it can be difficult to receive their input or opinion. Approach 2 only attempts to identify the model audience, which provides the perspective from which the model should be built. Here, stakeholders are only consulted during the final phases of the model building process. The steps for the four different phases of Approach 2 are also not as well defined and detailed as compared to Approach 1.

For the purpose of this study, Approach 1 is selected considering that the stakeholders had already identified a problem for this study. The approach also has well defined steps. Thus, Approach 1 is the preferred model building method and is used from here on onward. The last phase, *Implementation and learning lab*, will, however, be excluded from the model building methodology since it is not considered to be within the scope of this study owing to time constraints. The phase is also not considered vital in determining the implications of a green economy transition of food crop production in the Western Cape.

It needs to be noted that Approach 1 neglects the importance of model validation and testing during the modelling process and regard it as part of the *dynamic modelling phase*. Model validation is, therefore, incorporated as an additional phase into Approach 1. This additional phase is referred to as the *testing* phase. It consists of model validation tests and sensitivity analysis. Figure 3.3 illustrates the new adapted method, based on Approach 1, that is used as a guideline for this study.

The outline of the rest of the chapter follows the phases of Figure 3.3. The next section implements the problem structuring phase, after which the causal loop modelling, dynamic modelling and testing phases are implemented. The chapter ends with the scenario planning and modelling phase.

3.2 Problem structuring

During this phase of model development, the problem, scope and boundaries are defined. This is the first step for most problem-solving approaches according to Maani and Cavana (2012). They further argue that the importance of this step is mostly undervalued by managers and decision makers. This phase consists of identifying the problem areas or policy issues and collecting preliminary data.

3.2.1 Problem areas

The Western Cape government plans to implement a green economy in order to reduce GHG emissions and to create a more robust economy that is bound within the ecological constraints of the Province. This presents a challenge since current consumption and behaviour practices will need to change in order to adopt more sustainable practices. Another issue is that the current consumption patterns exceed natural resources limits (Western Cape Government, 2013*a*). There is also a concern for increasing drought conditions within the Province and it is predicted that the region will become even more water stressed in the future. The National Development Plan has a vision of transitioning South Africa to a low-carbon economy by 2030, but the Western Cape government has an extended socio-economic vision that is aimed at 2040 (Western Cape Government, 2013*a*,*b*).

In order to successfully transition to a green economy for agriculture, the Western Cape government has proposed *Smart Agri-production* as a solution (Western Cape Government, 2013*a*). The suggestion is that farming practices should be more sustainable and focus on soil quality and carbon sequestration. It is further suggested that farming in the Province should focus on input efficiencies including energy, water and nutrients. Organic and conservation farming practices meet these suggested requirements for sustainable farming and are, therefore, considered possible solutions.

There is, however, a problem that arises when yield per hectare for food crops are considered. On the one hand, organic farming is considered to have lower yield per hectare when compared to conventional farming practices (de Ponti *et al.*, 2012; Hough and Nell, 2002; Tuomisto *et al.*, 2012). Conservation farming practices (or no-till), on the other hand, have a slightly higher yield per hectare when compared to conventional farming practices, but are only applicable to grains (du Toit, 2007), while organic farming practices can be applied to all three food crop commodity categories (fruit, grains and vegetables) that are produced in the Western Cape.

While organic farming produces lower yields, it is expected that more agricultural land will be required than with conventional farming. It is, however, not clear if production would remain constant even if more land is used to produce food crops. There might also be a change in food crop price if there is an increase/decrease in food crop production. Another question that comes to the fore is whether organic farming would actually decrease GHG emissions (even if more agricultural land is required), and if so, how significant this decrease would be. The last question that must be addressed is what would the required financial investment be, if the province increased the food crop production area under organic and conservation farming practices.

3.2.2 Model boundary and time horizon

The model time horizon is set from 2001 (t_0) until 2040 (t_n). The model simulation starts at 2001, since (valuable) census data is available to initialise the model parameters, while historical data would allow for sufficient model behaviour validation. The year 2040 is chosen as the model stoppage time in order to compare predicted results with long-term goals. This also has the potential benefit that the Western Cape government could compare model results with their goals for their 2040 socio-economic vision. The boundary of the model can be defined as within the geological boundaries of the Western Cape, and the Province is viewed as a country on its own while the rest of South Africa is viewed as another country. Only the ten most significant (in terms of value or volume) food crop commodities in the province are modelled as categorised and listed in Table 3.1.

Table 3.1: The ten different farming commodities modelled

Food crop commodities		
Fruit	*Grains*	*Vegetables*
Apples	Wheat	Onions
Pears	Canola	Potatoes
Wine and table grapes	Barley	
Citrus fruit		
Stone fruit		

3.2.3 Preliminary information and data

Multiple public and private organisations were consulted in order to obtain useful data to improve the accuracy of the model and to help validate the model behaviour. The Department of Agriculture (DOA) releases annual reports with regard to the ten different commodities for South Africa. These reports typically have annual production for each province in volume, total area used for South African production, commodity price, and total exports for South Africa in monetary terms. Stats SA also conducts country wide censuses with regard to population at regular intervals. Some commodities detailed information are not publicly available, therefore, private organisations are consulted in order to obtain more detailed information. Table 3.2 shows the organisations that data is obtained from. The DOA and Stats SA are public organisations while

Table 3.2: Data sources used in model variables.

Variable	Data sources
Population	Stats SA; Quantec
Wheat	DOA; Quantec; SAGIS
Canola	DOA; Quantec;
Barley	DOA; Quantec;
Potatoes	DOA; Quantec; Potatoes SA
Onions	DOA; Quantec; KORKOM
Apples	DOA; Quantec; HORTGRO
Pears	DOA; Quantec; HORTGRO
Wine and table grapes	DOA; Quantec; SAWIS; SATGI; Hortgro
Citrus fruit	DOA; Quantec; CGA
Stone fruit	DOA; Quantec; Hortgro

Quantec, SAGIS, Potatoes SA, KORKOM, HORTGRO[1], SAWIS, SATGI, and CGA are all private organisations.

3.3 Causal loop modelling

In order to better understand the structure and behaviour of the food crop production system, CLDs are created. This helps to identify key role-players in the system and how these entities interact and influence each other. These CLDs provide the foundation for the stock and flow diagrams, and role-players can then be identified as either stock, flow, auxiliary, or exogenous variables.

Figure 3.4 illustrates a simple causal loop diagram that shows the systems structure and behaviour with regards to any given population. There are three variables, namely *births*, *population* and *deaths* (Maani and Cavana, 2012). If there are *births* then the *population* size will grow, therefore, the influence on *population* is positive (+) since *births* add to *population* size. The bigger the *population* the higher the birth rate since there are more individuals that can reproduce, and that, will in turn, bring about more *births* (+). This same logic applies to *population* and *deaths*. If there are *deaths*, *population* sizes will decrease, therefore, the influence on *population* is negative (−).

Reinforcing loops (R) are positive feedback systems (Maani and Cavana, 2012). This indicates that the feedback loop continues in the same direction. This results in either systematic growth or decline. The feedback loop is considered to be reinforcing (or positive) if it contains an *even* amount of negative causal links (−) (Kim, 1992).

[1]HORTGRO is an umbrella communication platform for a number of horticultural sectors. It co-ordinates many activities to ensure unity with focus on markets (demand), production (supply) and a range of cross-cutting industry functions, such as land reform, training and communication.

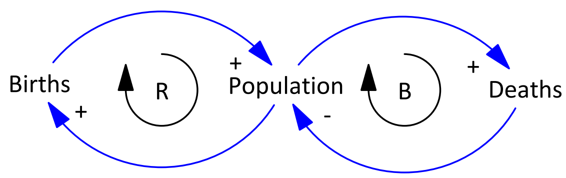

Figure 3.4: Basic population CLD (Maani and Cavana, 2012).

Balancing loops (B) are the opposite of reinforcing loops and are negative feedback systems (Maani and Cavana, 2012). This indicates that the feedback loop alters direction. This results in a fluctuation in the system or a move toward equilibrium (Haraldsson, 2000). The feedback loop is considered to be balancing (or negative) if it contains an *uneven* amount of negative causal links (−) (Kim, 1992).

3.3.1 Population and food demand CLD

Figure 3.6 illustrates a section of the expanded CLD (Figure 3.5) that describes the Western Cape's population and its main influences in the expanded CLD. Similar to Figure 3.4 this CLD has *births*, *population*, and *deaths*. Once again, the bigger the *population*, the more the *births*. An increase in *births* will lead to an increase in the *population*. An increase in *population* will also lead to and increase in *deaths*. The more the *deaths* the less the *population*, since *deaths* decrease population size.

Population size also affects food demand, and an increase in *population* will lead to an increase in *food demand*. This increase in *food demand* then negatively affects *food security*. If *food security* decreases, *food crop price* tends to increase, therefore, this relationship is negative (-). When *food crop price* increases, *food demand* will decrease. The behaviour of this feedback loop is balancing and is illustrated by loop B2 in Figure 3.6.

Feed back loop B3 depicts the effect exports has on food demand and food crop price. An increase in *exports* will lead to an increase in *food demand*. Similar to loop B2, an increase in food demand will result in a decrease in food security. An increase in *food crop price* will also result in a decrease in *exports*.

3.3.2 Food crop production CLD

The food crop production CLD of the Western Cape is indicated in Figure 3.7. Loop B4 indicates that this a balancing feedback loop. If food security decreases then food crop price will increase (similar as in Section 3.3.1). An

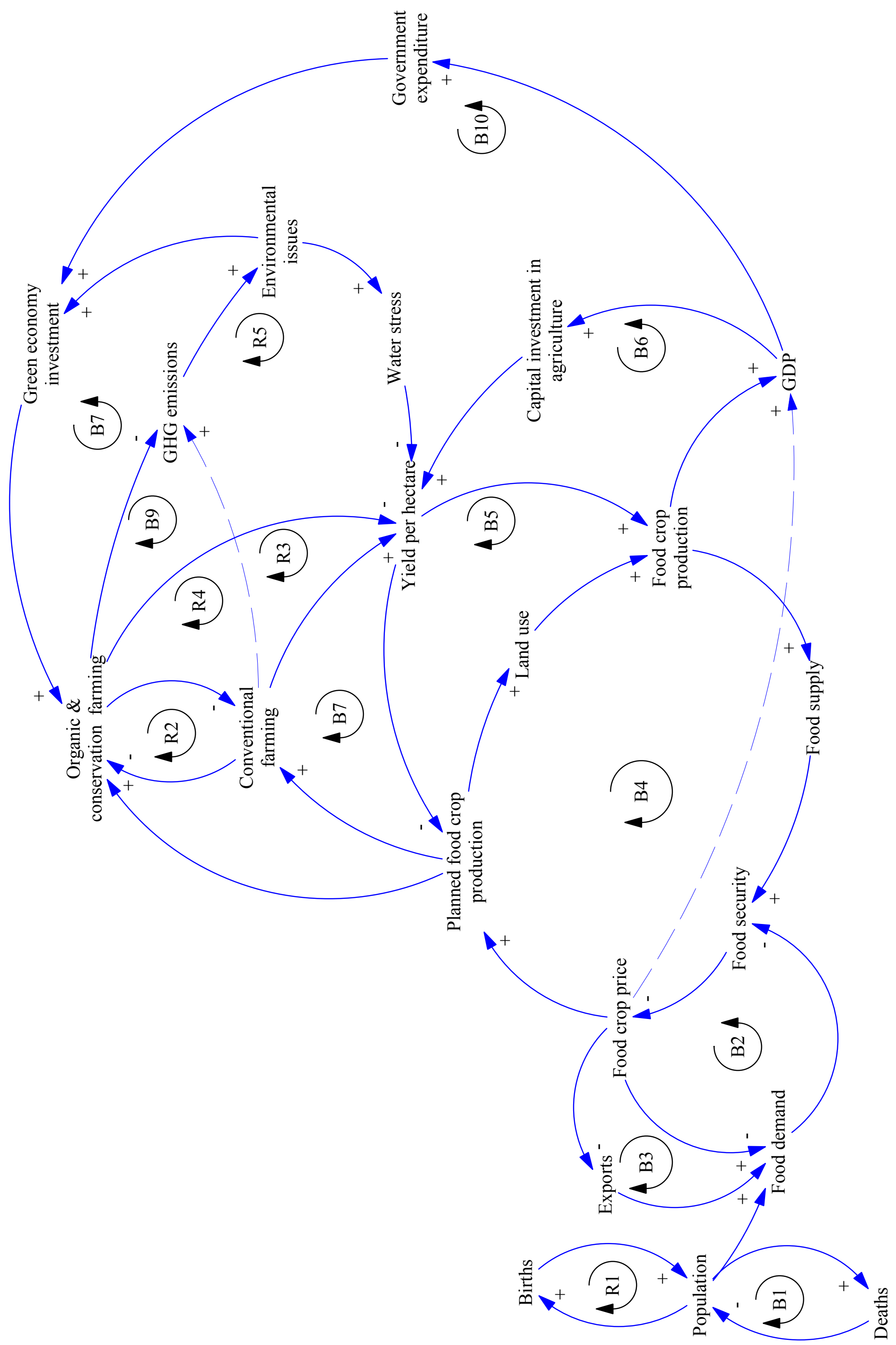

Figure 3.5: Expanded CLD for food crop production.

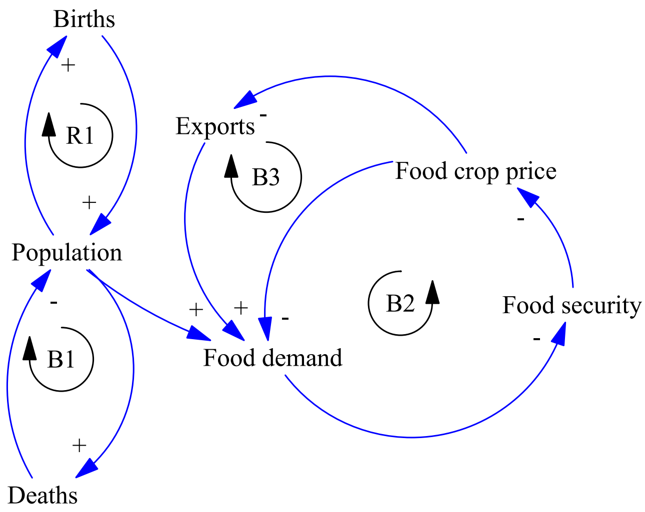

Figure 3.6: Population and food demand CLD.

increase in *food crop price* will result in an increase in *planned food crop production*, since farmers want to exploit this opportunity. If nothing else changes, then *land use* will increase in order to accommodate this increase in *planned food crop production*. This additional *land use* will then result in an increase in *food crop production* (if all other variable remain constant). *Food supply* in the Province will then increase as a result of the increase in *food crop production*, and improve *food security*. This increase in *food security* will reduce the *food crop price*.

3.3.3 Alternative farming options CLD

There are two alternative farming options for the food crop production sector of the Western Cape. Farmers could continue with current practices (conventional farming), or they can reduce GHG emissions from food crop production and adopt alternative farming practices such as organic and conservation farming. Figure 3.8 depicts the options that the farmers have and the impact of these alternatives on food crop production.

The effect of current practices is indicated in Figure 3.8 by the balancing feedback loop B5. If *planned food crop production* increases there will be an increase in one or both of *conventional farming* as well as *organic and conservation farming*. If *conventional farming* is chosen then the *yield per hectare* will increase and this will result in an rise in *food crop production* in the province. The rest of loop B5 is similar to that of loop B4 shown in Figure 3.7.

If farmers choose to implement *organic farming and conservation practices*,

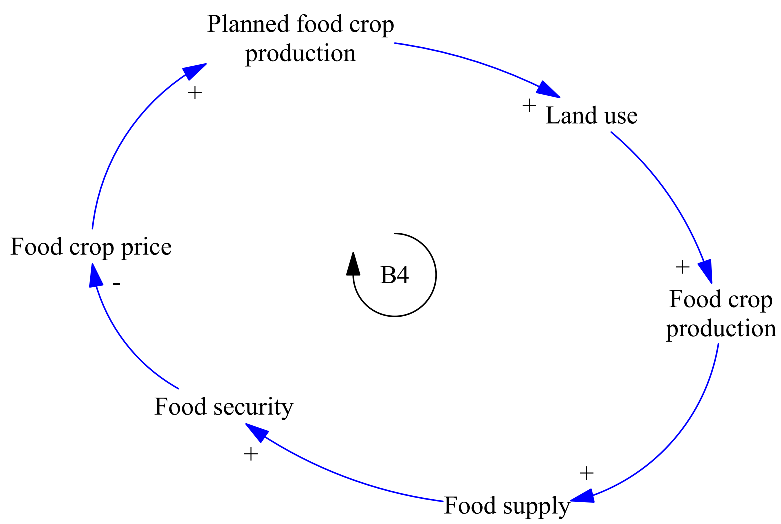

Figure 3.7: Food crop production CLD.

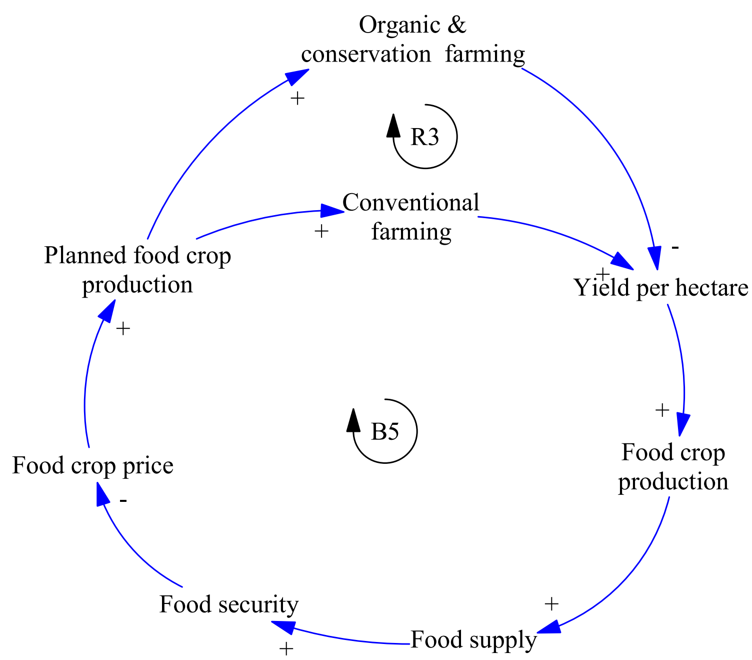

Figure 3.8: Farming options CLD.

then it is assumed that *yield per hectare* will decrease. If *yield per hectare* decreases, *food crop production* will also decrease, and this will result in an increase in *planned food crop production* if the rest of the feedback loop is followed. This leads to even more organic and conservation farming practices being adopted. Reinforcing feedback loop R3 depicts the described system behaviour when organic and conservation farming practices are implemented.

In Figure 3.8, the CLD's archetype is identified as *"fixes that fail"* (Maani and Cavana, 2012) since organic and conservation farming practices are implemented to reduce GHG emissions created from food crop production. However, more land is then required to produce the same volume of food crops produced by conventional farming since yield per hectare decreases with organic and conservation farming.

3.3.4 Food crop yield CLD

The food crop yield CLD is illustrated by Figure 3.9, and the effect the two alternative farming options have on planned food crop production. The CLD also exhibits how these two farming practices affect each other.

Conventional farming practices compete with organic and conservation farming practices, and this is illustrated by the reinforcing feedback loop R2 in Figure 3.9. They compete with each other in terms of percentage area utilised under each farming practice. Therefore, if more area is cultivated under *conventional farming*, then the area under *organic and conservation farming* decreases. The opposite is also true, if the area cultivated under *organic and conservation farming* increases, then *conventional farming* area decreases.

Both feedback loops R4 and B7 represent the behaviour these two farming practices have on planned food crop production indirectly through yield per hectare. If *organic and conservation farming*, increases then *yield per hectare* will decrease and results in farmers planning to produce more, which increases *planned food crop production*. When planned food crop production increases, the area under *organic and conservation farming* will also increase (reinforcing feedback loop R4). Balancing feedback loop B7 depicts how an increase in *planned food crop production* would increase the area under *conventional farming*, and result in improved *yield per hectare*. This improvement in *yield per hectare* will then decrease *planned food crop production*, since the farmer is satisfied and does not want to saturate the market.

3.3.5 Environment impact CLD

The impact on the environment due to production and how that changes model behaviour is indicated in Figure 3.10. Environmental issues are affected by GHG emissions both locally and internationally, but this CLD only considers local GHG emissions created from food crop production.

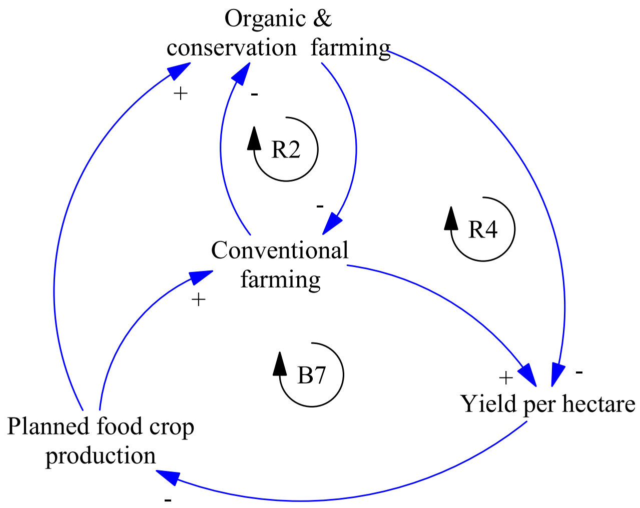

Figure 3.9: Food crop yield CLD.

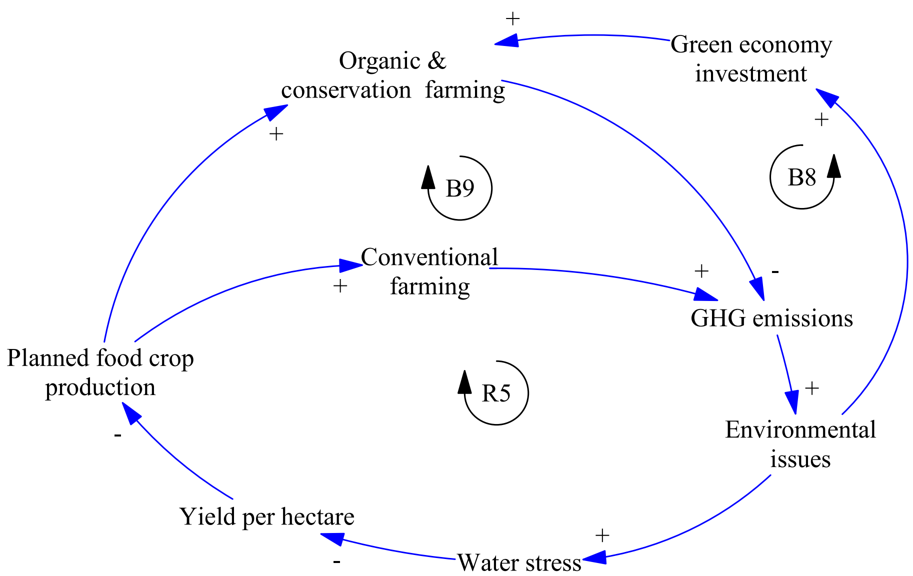

Figure 3.10: Environmental impact CLD.

Loop R5 is the only reinforcing feedback loop in this section and illustrates how *conventional farming* practices impact *GHG emissions* and ultimately *yield per hectare*. If there is an increase in *conventional farming*, then that would result in more *GHG emission* being created from food crop production. This increase in *GHG emissions* would then create more *environmental issues* and increase *water stress* within the province. Higher *water stress* levels in the province would negatively affect *yield per hectare* and result in more *planned food crop production*, in order to compensate for diminishing yields. This would in turn lead to more food crops being under *conventional farming* and increase *GHG emissions* even further.

Organic and conservation farming have the exact opposite impact on GHG emissions than conventional farming. If there is an increase in the food crop area under *organic and conservation farming practices*, then *GHG emissions* would decrease as compared to conventional farming. This will then lead to a decrease in *environmental issues* and lessen *water stress* and improve *yield per hectare*. This balancing feedback loop is represented by loop B9.

The last feedback loop in this CLD is the balancing feedback loop B8. This feedback loop represents how environmental issues would affect the food crop area under organic and conservation farming. An increase in *environmental issues* would result in an increase in *green economy investment*. This would then result in more food crop being produced with *organic and conservation farming* practices. *GHG emissions* would then decrease and result in reduced *environmental issues*.

3.3.6 GPD impact CLD

The last CLD section described is the impact GPD has on system behaviour. GDP, firstly, affects yield per hectare. If *GDP* increases, then more *capital investment in agriculture* will occur. When more capital is invested in agriculture, *yield per hectare* increases and this results in an increase in *food crop production*. If *food crop production* increases, then *GDP* will also increase. This is illustrated by balancing feedback loop B6.

Eyraud *et al.* (2011) argue that "green investment is boosted by economic growth". Therefore, it is amused that GDP also influences government expenditure, and increase in *GDP* will result in an increase in *government expenditure*. If the government has more money available, then *green economy investment* will also increase. As previously explained, an increase in *green economy investment* will lead to more food crops being produced with *organic and conservation farming* practices. *Yield per hectare* would decrease and *food crop production* would be negatively affected and *GDP* would decrease. This is all described by the balancing feedback loop B10.

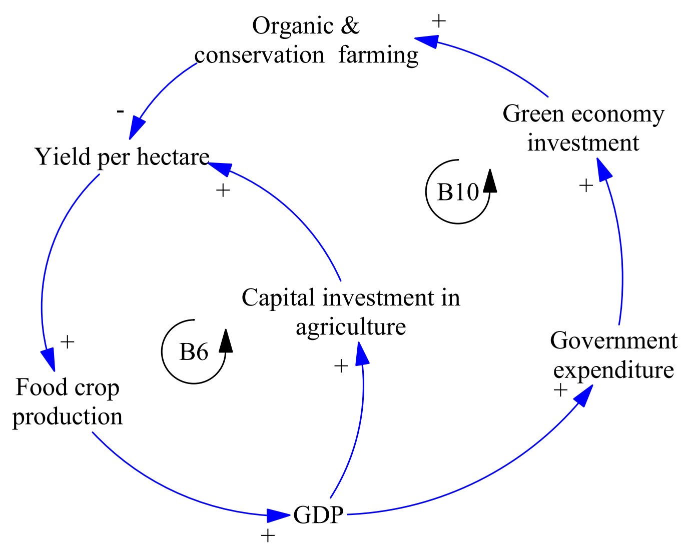

Figure 3.11: GDP impact CLD.

3.4 Dynamic modelling

The following section provides a description of each of the six stock and flow modules used to simulate the transition to green economy within the Western Cape's food cop production sector. The major stocks and flows of each module are described mathematically, and key variables and system dynamics are also discussed. Important assumptions with regard to input parameters and system behaviour are also noted for each module. Time variables t_0 and t_n are defined as 2001 and 2040 respectively as noted in Section 3.2.2.

3.4.1 Software used and simulation settings

Vensim was selected as the preferred modelling software due to it being more familiar to the model developer than STELLA. There are also more online resources and helplines available for Vensim than STELLA. The Euler method of integration is preferred over Runge-Kutta due the level of data uncertainty, speed requirements and lack of specificity-requirements (Musango *et al.*, 2015). Table 3.3 provides a summary of the simulation settings for Section 3.5 and Chapter 4. The time step is also set to 0.0625 to increase integration accuracy while not significantly sacrificing computation time.

Table 3.3: Simulation settings summary.

Software	Vensim DSS
Initial time (t_0)	2001
Final time (t_n)	2040
Time step	0.0625
Time units	Year
Integartion type	Euler

3.4.2 CLD elements in the different stock and flow modules

Section 3.3 described the CLD for the food crop production sector of the Western Cape, and divided it into six smaller overlapping CLDs. Elements of each of these CLDs are presented in the six stock and flow diagrams (SFDs) in this section and the systems behaviour is created. Table 3.4 provides a list of the different CLDs and SFDs. In this table, the check-marks (✓) indicate which SFDs contain elements of each one of the CLDs. Appendix A can be consulted to observe elements of the different CLDs in each SFD as indicated by Table 3.4.

3.4.3 Population module

This first module represents the population ($P(t)$) of the Western Cape and can be categorised according to age groups and sex. Some of the age groups, among others, are childbearing age, school age and adult age. The module has one stock variable, namely *population*, and is influenced by three different flow variables. Births (r_b) and net migration ($r_n i$) are inflow variables, while deaths (r_d) is a outflow variable. Equation 3.4.1 represents the population variable and the effects that the different flows have on this variable over time. Average adult literacy rate (social factor) influences births, while real GDP per capita (economic factor) influences deaths. A change in the population stock will affect food crop demand for the Western Cape. See Figure A.1 for the population module[2].

$$P(t) = P(t_0) + \int_{t_0}^{t_n} [r_b + r_{ni} - r_d]\mathrm{d}t \tag{3.4.1}$$

3.4.4 Agricultural yield module

The agricultural yield model represents the yield for all the 10 different food crop commodities that are consider for this model. Agriculture capital ($AC(t)$)

[2]This population module was presented as part of a paper at the 33rd International Conference of the System Dynamics Society in Cambridge, USA (Musango *et al.*, 2015).

Table 3.4: Elements of the CLD's in the different dynamic modules.

CLD's	**Dynamic modules**						
	Population	Agricultural yield	Food crop production	Food crop price	Emissions	Green economy investment	Other modules
Population and food demand	✓		✓	✓			
Food crop production			✓	✓			
Alternative farming options			✓		✓	✓	
Food crop yield		✓	✓				
Environment impact		✓			✓		
GPD impact		✓					✓

is the only stock variable in this module. There is one inflow variable in the module, namely gross agriculture capital formation (r_{acf}). Agriculture capital depreciation(r_{acd}) is the only outflow variable that influences the agriculture capital. Equation 3.4.2 represents the agriculture capital variable and the effects of the different flows over simulation time. See Figure A.2 for the agricultural yield stock and flow module.

$$AC(t) = AC(t_0) + \int_{t_0}^{t_n} [r_{acf} - r_{acd}]\mathrm{d}t \tag{3.4.2}$$

Capital investment into the agricultural sector and water stress are the two variables that influence yield per hectare for each of the food crops. It should be noted that organic and conservation farming also affects yield per hectare. Organic farming can be applied to all three food crop categories, namely fruit, grains and vegetables. Conservation farming can, however, only be applied to grains due to technology and farming practice constraints.

This module also calculates the effect water stress has on yield for each of the farming commodities. It is assumed that grains are the least sensitive to water stress, followed by vegetables and fruit. The water stress level for the Western Cape is assumed to be similar to that of South Africa, and was, therefore, obtained from the SAGEM report (Musango *et al.*, 2014). See Figure A.3 for the water stress module that forms part of the agricultural yield module.

The demand for each food crop commodity is also calculated in this module (see Figure A.4). Demand is a function of requirements of the Western Cape's population (local demand) and a function of exports. Exports are regarded as food crops that are exported from the Province either overseas or to the rest of South Africa. The Western Cape Province is assigned a percentage responsibility of the requirements for the population demand for the rest of South Africa according to its contribution to total production for each commodity from a country wide perspective.

The last function of this module is to calculate the area planted for each food crop commodity. The area planted for each food crop commodity is influenced by food crop price and average yield per hectare. The sum of all the different food crop commodity areas are also used to determine the total area of land used for food crop production (see Figure A.5).

3.4.5 Food crop production module

This module represents the food crop production for the Western Cape's agriculture sector. Production is divided into the three food crop categories, namely: grain, fruit, and vegetables. The module contains no stocks or flows, but is rather a combination of different variables that are used from other modules to determine annual food crop production. See Figure A.6 to A.8 for module structure of Western Cape food crop production.

Grain production per year is a function of annual conventional, organic, and conservation crop production. Fruit and vegetable production per year, in turn, are only functions of annual conventional and organic production as noted in section 3.4.4.

3.4.6 Food crop price module

The fourth module is the food crop price module, which depicts the price for each commodity in rand per ton (R/ton). This module has six stock variables and twelve flow variables. The first stock variable is grain stock ($GS(t)$), and represents the stock levels for wheat, canola, and barley. There is one inflow variable into the stock, namely annual grain production (r_{agp}). It should be noted that grains are seldom exported from South Africa, considering that the production is marginally less than consumption for the country. For that reason, it is assumed that the Western Cape prioritises its local demand (r_{algc}) before it exports to the rest of South Africa (r_{age}). The grain stock variable is represented by Equation 3.4.3.

$$GS(t) = GS(t_0) + \int_{t_0}^{t_n} [r_{agp} - r_{algc} - r_{age}]\mathrm{d}t \tag{3.4.3}$$

The demand to supply imbalance then affects grain price for each of the three commodities. Grain price ($GP(t)$) is the second stock variable in this module and is affected by change in grain price (r_{cigp}). Equation 3.4.4 depicts grain price as being a function of initial grain price ($GP(t_0)$) and the change in grain price. Figure A.9 depicts the stock and flow module of grain stock and price.

$$GP(t) = GP(t_0) + \int_{t_0}^{t_n} r_{cigp}\mathrm{d}t \tag{3.4.4}$$

The vegetable stock ($VS(t)$) is the third stock variable, functions similar to that of grain stock, and represents the stock levels for both potatoes and onions in the Western Cape. Again, South African vegetable consumption is marginally more than production, therefore vegetables are seldom exported. This results in vegetable stock having similar behaviour to grain stock, in that local demand (r_{alvc}) is prioritised before vegetables are exported to the rest of South Africa (r_{ave}). Vegetable stock increases through annual vegetable production (r_{avp}). This is mathematically illustrated by Equation 3.4.5.

$$VS(t) = VS(t_0) + \int_{t_0}^{t_n} [r_{avp} - r_{alvc} - r_{ave}]\mathrm{d}t \tag{3.4.5}$$

As with grain price, vegetable price ($VP(t)$) is also affected by the demand supply imbalance. Vegetable price is the fourth stock variable is this module and is influenced by the change in vegetable price (r_{civp}). See Figure A.10 for the stock and flow module of vegetable stock and price.

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

The fifth stock variable in this module is fruit stock ($FS(t)$) and represent the stock level of apples, pears, citrus fruit, stone fruit as well as the wine and table grapes for the Province's fruit production. Fruit stock increases through annual fruit production (r_{afp}), which is an inflow variable. Fruit stock is also influenced by local demand (r_{alfc}) and fruit export demand (r_{afe}). Due to international fruit exports being of significant value to the Province's GDP, it is assumed that export demand is regarded as the main priority for the Western Cape. This is followed by local demand and then rest of South Africa's demand. Equation 3.4.7 is a mathematical representation of fruit stock.

$$FS(t) = FS(t_0) + \int_{t_0}^{t_n} [r_{afp} - r_{alfc} - r_{afe}] \mathrm{d}t \tag{3.4.7}$$

The last stock variable in this module is fruit price ($FP(t)$), and functions exactly the same as grain price and vegetable price. The flow of change in fruit price (r_{cifp}) affects the fruit price for each commodity and is embodied in Equation 3.4.8. Figure A.11 depicts the stock and flow module of fruit stock and price.

$$FP(t) = FP(t_0) + \int_{t_0}^{t_n} r_{cifp} \mathrm{d}t \tag{3.4.8}$$

3.4.7 Emissions module

This module depicts the GHG emissions created from food crop production for the Western Cape. These emissions are categorised according to the three different farming practices, namely conventional emissions, organic emissions and conservation emissions. The module consists of one stock variable and has one flow variable. Total agriculture GHG emissions ($TAE(t)$) is the accumulated value of the annual emissions from food crop production. Annual agriculture production emissions (r_{aape}) is the inflow of emissions created by food crop production on yearly basis. Equation 3.4.9 is a mathematical representation of total agriculture GHG emissions.

$$TAE(t) = TAE(t_0) + \int_{t_0}^{t_n} r_{aape} \mathrm{d}t \tag{3.4.9}$$

Conventional emissions per area are specific for each one of the ten different food crop commodities. For organic emissions per area, the emissions are considered to be a percentage of conventional emissions and these percentages are only category specific, namely: grains, fruit, and vegetables. Conservation emissions only apply to grains (as previously mentioned in Section 3.4.4) and are also considered a percentage of conventional emissions. Figure A.12 illustrates the module's structure with regard to stock, flows and other variables.

3.4.8 Green economy investment module

The last module used is the green economy investment module and represents the additional costs required for different green economy investments (see Figure A.13). Agriculture investment ($AI(t)$) is the only stock variable in this module. This is influenced by the inflow of annual agricultural investment (r_{agi}), and Equation 3.4.10 is a mathematical representation of agriculture investment.

$$AI(t) = AI(t_0) + \int_{t_0}^{t_n} r_{agi} \mathrm{d}t \tag{3.4.10}$$

It is assumed that organic farming will be more expensive than conventional farming per unit area, due to government regulations. Conservation farming is, however, regarded as less expensive than conventional farming per unit area, due to no-till farming practices reducing production costs according to Lankoski *et al.* (2006).

3.4.9 Other modules used

Other modules that were used in this model but not discussed are GDP, education, provincial land, and the agricultural land modal split module. These modules from part of an overlapping research effort that aims to better understand the implications of a green economy on the Western Cape economy (Musango *et al.*, 2015). The GDP module [3] is used by the population and agricultural yield modules. The education module[4] is used by the population model and affects fertility rate. The provincial land module[5] has an effect on the agricultural yield module by influencing capital per hectare. The agricultural land modal split model contains no stocks, but represents the area allocation between conventional, organic, and conservation farming practices.

[3]The GDP module was presented as part of a paper at the 33rd International Conference of the System Dynamics Society in Cambridge, USA (Musango *et al.*, 2015).

[4]The education module was presented as part of a paper at the 33rd International Conference of the System Dynamics Society in Cambridge, USA (Musango *et al.*, 2015).

[5]The provincial land module was presented as part of a paper at the 33rd International Conference of the System Dynamics Society in Cambridge, USA (Musango *et al.*, 2015).

3.5 Testing

Before the model can be used for policy analysis or scenario testing, a certain amount of confidence should be gained in model and model results. In order to achieve a satisfactory level of confidence in the model, it needs to be tested. Model validation and sensitivity analysis are the two major steps of model testing. Maani and Cavana (2012) argue that there is no single test that serves to validate a SDM. They argue that confidence in the model is rather gradually gained as more tests are conducted. Sargent (2013) finds that a combination of tests are generally used in order to evaluate and validate a simulation model. Forrester and Senge (1980) also argue that "*as a model passes more tests and as new points of correspondence between the model and empirical reality are identified*" confidence in the model accumulates. Sterman (2000) concludes that a model cannot be validated using a single test or judging the model's ability to fit historical data.

Barlas (1996) categorises SDM validity into two main categories, namely *structure validity* and *behaviour validity*. Structure validity can be further broken down into *direct structure tests* and *structure-oriented behaviour tests* (Barlas, 1996). Direct structure tests determine the validity of the model structure by comparing it directly to knowledge about real system structure. Structure-oriented behaviour tests determine the validity of the model structure indirectly by preforming behaviour tests on model simulation patterns. Vlachos *et al.* (2007) note that for structure-oriented behaviour tests (or *indirect structure tests*), the two most common tests are extreme-condition and behaviour sensitivity tests. After enough confidence is gained in the model, behaviour validity test can be applied to the model. This test measures how accurately the model can reproduce the major behaviour patterns displayed by the real system. Barlas (1996) highlights the importance of the word *pattern* prediction, rather than point prediction when carrying out behaviour validity tests.

Historical data should be used to validate the model if it exist according to Sargent (2013). He states that historical data can be used to determine if the model behaves as the real system does. Maani and Cavana (2012) also have a set of guidelines/steps that can be used to validate and build confidence in a SD model as listed below:

- The CLD must correspond to the problem being modelled.
- Equations must correspond to the CLD. Signs in the equations must match the signs in the CLD.
- The model must be dimensionally valid.
- The model must not produce any unrealistic values.
- The behaviour of the model must be plausible.
- The model should maintain *conservation of flow*.

3.5.1 Guideline tests

The model is, firstly, validated by following Maani and Cavana (2012) guidelines/steps as described above. The first step is to determine if the CLD corresponds to the problem at hand. Figure 3.5 represents the expanded CLD for the food crop production systems. It encapsulates the problem that the food crop production system faces, by illustrating the the effect and uncertainty surrounding sustainable farming practices, growing population, food demand and GHG emissions.

The second step is to analyse if all SFD equations signs match that of the CLD. This was done for SFD variables that correspond or represent CLD variables and the equations signs match. An example is that if population increases, then food demand should also increase according to the CLD. When this is compared to the equation for *Domestic grain requirements* in the SFD, the equation reads:

$$\begin{aligned} \textit{Domestic grain requirements} = \textit{Grain requirements per person} \times \\ \textit{Total population} \times \textit{Effect of price on grain demand} \end{aligned} \tag{3.5.1}$$

Equation 3.5.1 illustrates that if the other two variables remain constant and population increases, then domestic grain requirements will also increase.

The third step is to ensure that the model is dimensionally valid. This means that the dimensions of the variables on the right-high side should be able to be converted to the dimensions on the variables on the left-hand side of the equations. Vensim has a function that tests the whole SFD's dimensions and returned *Units are A. O. K.*

The fourth step as described by Maani and Cavana (2012), is to ensure no unrealistic values are produced by the model. This step shares a close link to step five, which states that the behaviour of the model should be plausible. Steps four and five are, therefore, done at the same time. The model variables produce no unrealistic values and the behaviour of different variables are plausible.

The last step is to determine whether the model maintains *conservation of flow*. The total quantity of each variable should be accounted for in terms of what has entered, left or, is still in the system. There are a total of 19 stock variables from the different sub modules as described in Section 3.4. All 19 variables were tested and it was determined that the model maintains *conservation of flow*.

3.5.2 Extreme-condition test

Extreme-condition tests are conducted by assigning extreme values to certain model variables/parameters, and comparing the results to determine if they are plausible. In order to increase the validity of an extreme-condition test, it can be computed and then compared to the real system when it experienced similar extreme conditions. Vlachos *et al.* (2007) argue that humans struggle to anticipate a complex systems dynamics and behaviour under arbitrary operating circumstances. They explain that humans are able to better anticipate a complex systems behaviour under extreme circumstances.

Multiple extreme-condition were conducted analysing model variables such as *initial yield*, *food requirements per person*, *income per capita*, *natural fertility rate*, *elasticity of yield to water stress*, and *desired grain demand/supply ratio*. There were, however, no historical extreme conditions that the real system experienced to compare results with. All the extreme-condition tests results appeared feasible.

An example of one of the tests was when initial yield of wheat was decreased 6.5 times (from 1.95 to 0.3 tonnes per hectare). Under these extreme conditions, the area used to produce wheat increases to almost double that under normal conditions. The wheat production (in ton) is about a third of what was produced under normal circumstances while the wheat price increased to unaffordable levels. This appears to be plausible given the severity of the decrease in yield per hectare.

3.5.3 Sensitivity analysis

Maani and Cavana (2012) argue that some initial parameters, conditions and structural relationships are estimated during model construction owing to the lack of information. It is for this reason that a sensitivity analysis is performed on certain model variables in order to understand how the model's behaviour may change when uncertain values are verified. Vlachos *et al.* (2007) explain that performing a sensitivity analysis helps to identify the parameters to which the model is extremely sensitive. This also helps to determine if these sensitivities in the model make sense in the real system that is being modelled.

The main variables that were assumed during model development are expected to be sensitive, and they are primarily the different elasticities in the model. These elasticities represent behavioural changes a certain variable undergoes when another variable's relative value changes. Furthermore, the model is also expected to be extremely sensitive to initial values such as yield, population and food requirements per capita.

Figure B.1 and Figure B.2 represent two sensitivity analysis tests that were conducted to test the model's sensitivity to one of the elasticity variables. The elasticity variable that was identified for this test is *grain price demand elasticity* (see Figure A.9). This variable represents how consumer demand will be affected by the change in price relative to the initial price. Both Figure B.1 and Figure B.2 indicate that both *wheat price* and *wheat production* are very sensitive to this variable, and that is as expected. If consumer demand is affected less by an increase in wheat price, then wheat price will go up (due to demand increasing) and farmers will plant more (due to higher price) in order to increase revenue.

A second sensitivity analysis test was performed in order to determine the sensitivity of the model in terms *annual agriculture production emissions* and *annual agricultural investment*. The variable under inspection was *initial fruit area required per type*, but focusing on *apples*. The results are graphically represented in Figure B.3 and Figure B.4. Annual agriculture production emissions appear to only be slightly sensitive to a change in initial area at the start, after which the system resumes its normal behaviour (see Figure B.3). The annual agricultural investment has no sensitivity towards a change in initial area as illustrated in Figure B.4. This can be explained by the fact that investment into the green economy only started in the year 2015, and (as noted from Figure B.3), the impact of this change affects the systems behaviour in the short-term.

3.5.4 Historical data tests

As earlier mentioned (see section 3.5), Sargent (2013) argues that historical data should be used (if it exists) to determine if the model has similar behaviour to the real system being modelled. Each of the ten different food crop commodities have historical data available in terms of annual production, area used, yield per hectare, and price. The data was obtained using the sources identified in Table 3.2. Examples of the historical data test are shown in Figure 3.12 to 3.14.

Onion production results from the model is compared to historical production data in Figure 3.12. The historical behaviour of the model appears volatile over the short-term, however, the onion production in the Province increases as time progresses. The model results follow the general trend of the historical data and also increases as time progresses. Production growth, however, appears to be diminishing over time. This model behaviour is expected when comparing historical data to simulated results for onion production.

The price of pears can also be compared to historical data and this comparison is illustrated in Figure 3.13. The models simulated behaviour is similar to that of the real system when its historical data is compared. The historical price for pears increases gradually as time progresses and the model's simulated price follows this closely.

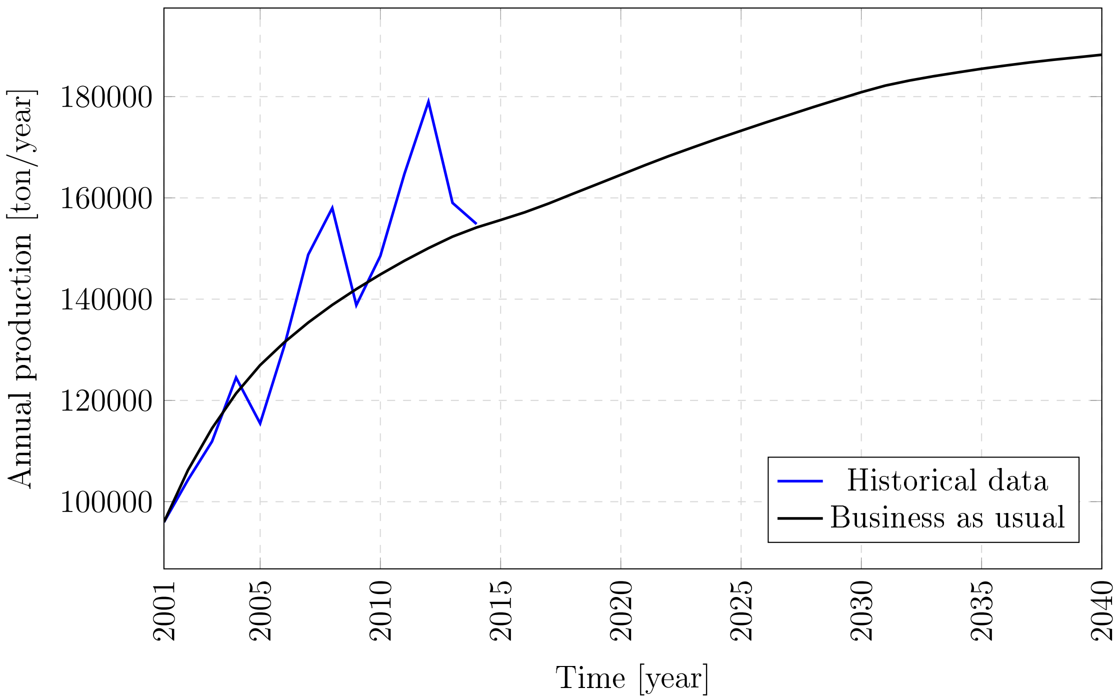

Figure 3.12: Annual onion production for Western Cape ($\sqrt{R} = 0.765$).

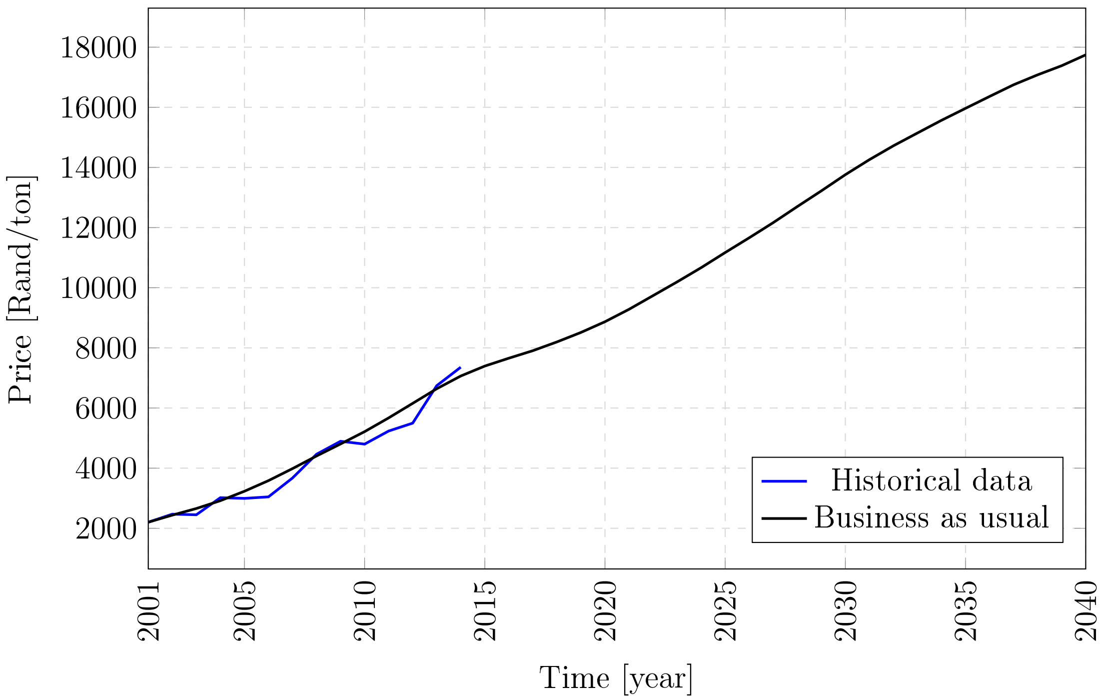

Figure 3.13: Pear price for each year ($\sqrt{R} = 0.956$).

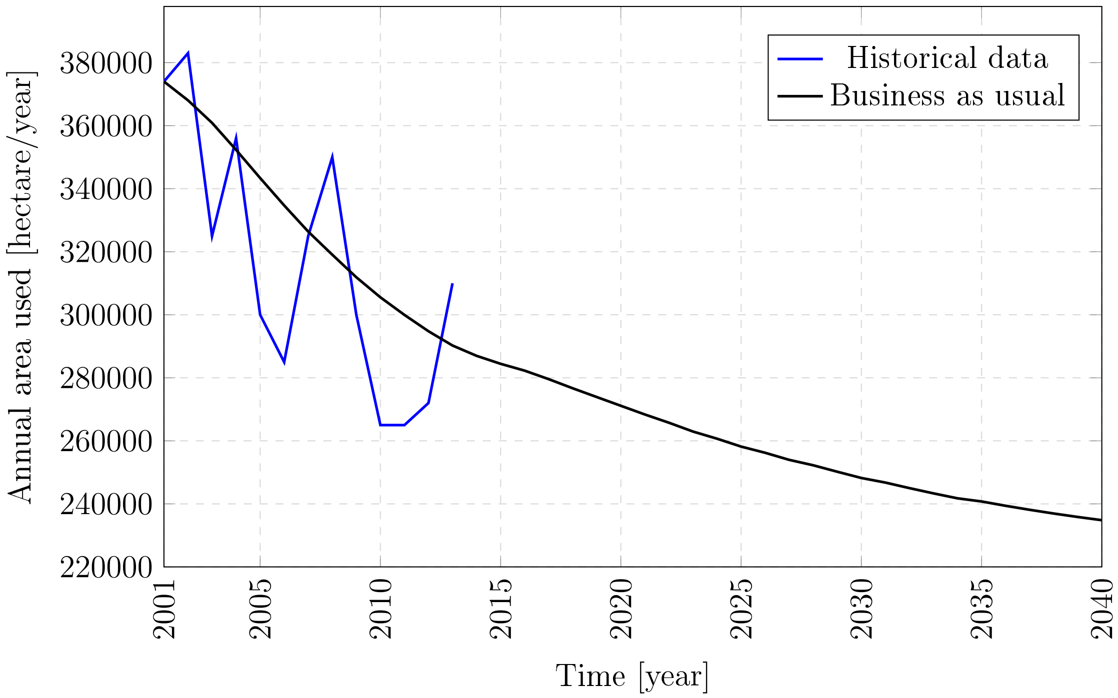

Figure 3.14: Annual area used for wheat production in the Western Cape ($\sqrt{R} = 0.446$).

Another example of a historical data test is when the annual area used for wheat production in the Western Cape is compared to model results and behaviour. Figure 3.14 represents the comparisons between the two. The real system appears to be steadily decreasing with some fluctuations, while the model's behaviour also shows a gradual decrease over simulated time. Again model behaviour is regarded as expected when compared to the real system's behaviour.

3.5.5 Validation summary

Table 3.5 contains a summary of the model validation tests performed in Section B. The first column lists the four different tests performed, namely guideline tests, extreme-condition tests, sensitivity analysis and historical data tests. The second column lists the elements examined by each test, and the last column summarises the findings. Overall, there is enough confidence in the model and it is viewed as acceptable. For more historical data tests refer to Appendix D to F.

Table 3.5: Model validation summary.

Test type	**Elements tested**	**Conclusion**
Guideline tests	CLD compared to problem at hand, CLD compared to equations in SFDs, dimension validity of model, no unrealistic values, plausible model behaviour, conservation flow is maintained	The model fulfilled each of the guideline tests.
Extreme-condition tests	Initial yield, food requirements per person, income per capita, natural fertility rate, elasticity of yield to water stress, desired grain demand/supply ratio	The model behaved as expected under extreme conditions.
Sensitivity analysis	Grain price demand elasticity • Wheat price • Wheat production Initial fruit area required per type • Annual agriculture production emissions • Annual agricultural investment	The model is sensitive to each elasticity and this is expected. The model is also sensitive to initial values.
Historical data tests	Onion production, pear price, wheat area used	The ten different commodities' behaviour follows that of historical data in terms of price, production, and area used. Some are, however, more accurate when $\sqrt{R}$ values are considered.

3.6 Scenario planning and modelling

Scenarios for the model are developed according to the *Green is Smart: Western Cape Green Economy Strategy Framework 2013* (Western Cape Government, 2013*a*). The framework identifies sustainable farming practices as the major goal for agriculture to form part of the green economy. Other initiatives for improvement are energy efficiency cooling, water efficiency technologies, beneficiation of waste, climate-related agricultural research and food security. Sustainable farming practices, however, remain the major drivers moving current agricultural food crop production towards compliance with the green economy framework.

Organic and conservation farming practices are considered the two options for achieving more sustainable food crop production system. There are, however, numerous concerns regarding yield per hectare for organic farming (as noted in Section 3.2.1). These concerns are, therefore, incorporated into the different modelling scenarios. Research with regard to grain yields under conservation farming practices indicated that yields are marginally higher when compared to conventional farming practices. There are four different scenarios and each scenario is described in detail in this section. The parameter values for each scenario and modelling results are described and discussed in Chapter 4.

3.6.1 Scenario 1: Business as Usual

The first scenario is called *business as usual* (BAU), and represents the systems behaviour if it were to continue with current practices. Here, conventional farming practices are considered the preferred methods of producing food crops, with conservation and organic farming practices contributing significantly less. Investment into sustainable farming practices (green economy investment) are also minimal due to the preference for commercial farming with conventional methods. This scenario predicts future system behaviour and sets the baseline for comparison with the green economy scenarios.

3.6.2 Scenario 2: Green Economy Worst Case

The second scenario for this research is called *green economy worst case* (GEWC). This modelling scenario simulates system behaviour if organic yields per hectare are significantly less than those of conventional farming. Since this is a green economy type scenario, organic and conservation farming practices are applied considerably more with regard to food crop production. The aim is to reduce GHG emissions and as a result, green economy investment will increase. Food crop production and land used for production will also be affected due to more crops being produced with sustainable farming methods. This scenario adopts a pessimistic view toward organic yield per hectare.

3.6.3 Scenario 3: Green Economy Realistic Case

The third model scenario is *green economy realistic case* (GERC). This scenario is similar to GEWC, in terms of food crops being produced under the same percentage of organic and conservation farming practices. The scenario also has the same primary aim of reducing GHG emissions produced by food crop production. The main difference is, however, in the yield per hectare for organic food crops. The yield per hectare in this scenario is slightly more than with GEWC, but still less than that of conventional farming. This scenario adopts neither a pessimistic or optimistic point of view, but rather views organic practices in a conservative way.

3.6.4 Scenario 4: Green Economy Best Case

The last green economy scenario is an optimistic scenario and is called *green economy best case* (GEBC). This scenario is similar to GEWC and GERC in terms of food crops being produced under the same percentage of organic and conservation farming practices. The notable difference in GEBC as compared to the other two green economy scenarios, is that organic yield is regarded to be the same as conventional farming practices. This scenario depicts what the system behaviour and investment cost would be if organic yield per hectare can be improved to be equal that of conventional farming. Here, the potential (if any) future benefits of sustainable farming practices are highlighted.

3.7 Conclusion: Modelling approach

This chapter identified and explained two different modelling approaches that can be used as guidelines in order to build a system dynamics model. Method 1 is subsequently chosen as the preferred modelling guideline. The problem areas with regard to sustainable farming (organic and conservation) are highlighted while identifying the potential value of the research. Preliminary data sources are also listed in this chapter. An in-depth discussion of the casual loop diagram, which helps to conceptualise the problem at hand and system behaviour, also formed part of this chapter. Major stock and flows are discussed for all the stock and flow diagram modules that interact to form the dynamics of the whole system. Model testing and validation is the penultimate topic of discussion in the chapter, and this is followed by identification of modelling scenarios. The four different modelling scenarios, namely business as usual, green economy worst case, green economy realistic case and green economy best case are also discussed.

The next chapter discusses the different results obtained from the four different scenarios. In Chapter 4 the modelling results are discussed in detail and represented graphically.

Chapter 4

Modelling Results

As described in Chapter 3, *scenario planning and modelling* is fifth phase in the process of systems thinking and modelling. The scenario planning was concluded in Section 3.6, but the scenarios still need to be simulated and that is the purpose of this chapter.

This chapter discusses the modelling results for each of the four scenarios in terms of model outputs such as population, food crop price, food crop production, area used, GHG emissions, and green economy investment. Results from this chapter can then be used to give recommendations to stakeholders in order to better manage this transition to a green economy.

In this chapter, the model scenarios input parameters are quantified and discussed. The model is then simulated with these different input parameters in order to obtain model results. Lastly, different model output variables are discussed and how the four scenarios affected these variables.

4.1 Model scenarios input parameters

Before the model scenarios can be simulated, the input parameters need to be defined. Section 3.6 provides a detailed description of each one of the four scenarios, but just to summarise, each of the scenarios are described briefly again. Business as usual (BAU) is how the system will behave if current practices continue. GEWC is a pessimistic view with regard to organic yield, with an increase in sustainable farming practices. GERC is a conservative opinion toward organic yield, the yields are, however, more than those expected from GEWC. GEBC is an optimistic take on organic yield and it is assumed that organic yield can match that of conventional farming practices.

In all three green economy scenarios (GEWC, GERC, and GEBC) the percentage of food crops produced under organic and conservation farming practices are significantly more than with BAU scenario, while the aim is to keep them realistic and achievable. Recent research has shown that conservation farming (no-till) practices can have up to 33% more yield than conventional farming in the Western Cape (Venter, 2015). A conservative approach is, however, followed and conservation yield is regarded as being slightly more than conventional yield per hectare.

Table 4.1 summarises the different input parameters for the four different scenarios. All of the scenarios only start in the year 2015 and aim to achieve these percentage areas by 2040. All crops are assumed to be produced with only conventional farming from 2001 until 2015 from where conventional farming is gradually decreased and replaced with organic and conservation practices until they reach their defined percentage areas as reflected in Table 4.1.

Table 4.1: The four different model scenarios input parameters.

Input parameters	Modelling Approaches			
	BAU	*GEWC*	*GERC*	*GEBC*
Yield vs. conventional				
Organic	75%	65%	75%	100%
Conservation	115%	115%	115%	115%
Production area				
Conventional	80%	45%	45%	45%
Organic	5%	15%	15%	15%
Conservation	15%	40%	40%	40%

For BAU, organic and conservation yield per hectare are considered to be 75% and 115% of conventional yield respectively. It should also be noted that the vast majority of food crops are still produced with conventional farming practices (80%) when compared to organic (5%) and conservation (15%) farming practices by 2040. For GEWC, organic yield is assumed to be lower and is set at 65% of that of conventional yield. Conservation yield per hectare remains the same as with BAU, when compared with conventional yield. Food crops produced with organic and conservation farming practices also increases to 15% and 40% respectively for GEWC, while conventional farming practices decrease to 45% by 2040. The variables for GERC and GEBC remain the same when compared to GRWC, except for their organic yields. GERC's organic yield is set at 75%, since this is viewed as realistic and achievable, while GEBC's organic yield is set at 100% and is viewed as optimistic.

4.2 Population

The population of the Western Cape has shown rapid growth between the years 2001 and 2011; this is graphically represented in Figure 4.1 by the historical data. The four different model simulations have similar findings and also

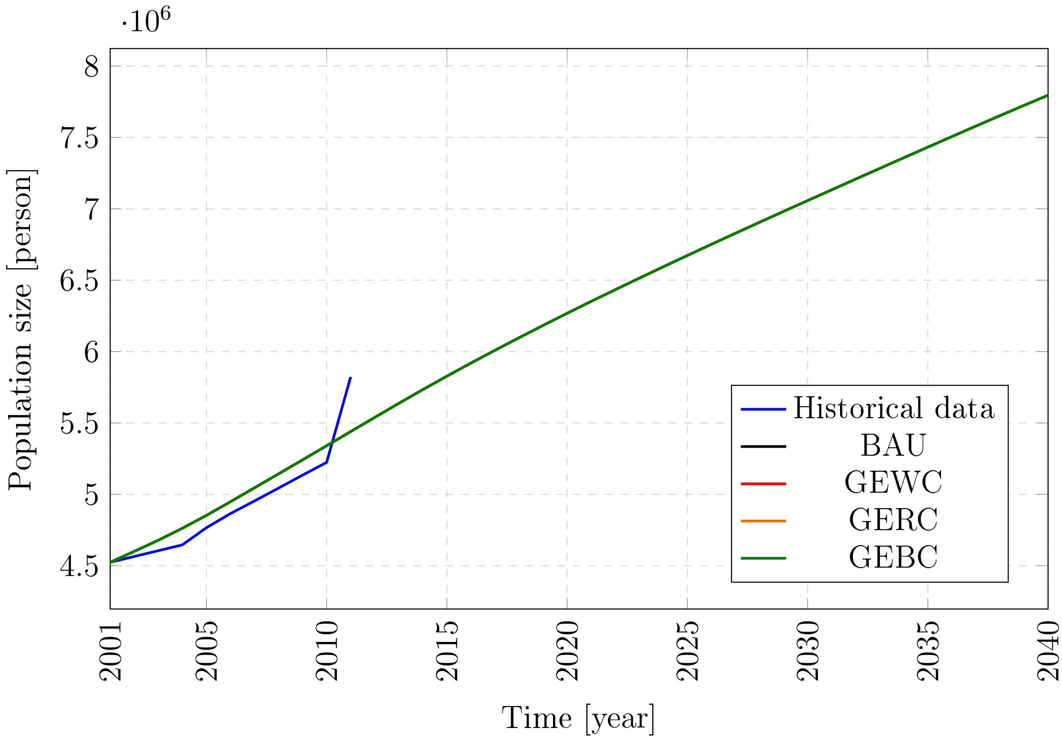

Figure 4.1: The estimated Western Cape population size.

predict a steady increase in the Western Cape's population until 2040. The initial population size was 4.52 million in the year 2001.

All four model scenarios have the exact same behaviour towards the population growth. This is primarily due to the fact that food crop production has no effect on the Western Cape's GDP, and is a result of how the GDP SFD was built. The GDP model only uses exogenous variables and, therefore, the population remains unaffected by other system changes.

The population of the Western Cape is, however, projected to be 7.8 million in the 2040. This means that population will increase by roughly 3.3 million citizens over this 39 year period. Population growth is also projected to decrease in the long-term, when compared to the rapid initial growth witnessed in the historical data.

4.3 Yield per hectare

The second notable output from the model is yield per hectare for the ten different food crop commodities produced in the Western Cape. Table 4.2 summarises the simulation results for the four different scenarios. The table categorises the results per scenario and lists the results of each of the ten commodities for that specific scenario.

Table 4.2: A summary of the scenarios' yields for the ten different farming commodities (*ton/hectare*).

Commodity	Time							
	2001	2010	2015	2020	2025	2030	2035	2040
BAU								
Citrus	32.0	36.4	37.1	37.0	38.4	39.7	40.2	40.6
Apples	21.8	32.6	37.3	40.4	44.9	49.1	51.8	53.9
Wine and Table grapes	10.5	13.4	14.4	14.8	15.8	16.7	17.3	17.7
Stone fruit	13.7	16.3	16.9	17.0	17.9	18.6	19.0	19.3
Pears	21.1	30.0	33.5	35.8	39.2	42.4	44.4	46.0
Wheat	2.0	2.4	2.6	2.8	3.0	3.1	3.2	3.3
Canola	1.0	1.2	1.4	1.5	1.6	1.6	1.7	1.8
Barley	1.7	2.6	3.0	3.5	3.9	4.2	4.5	4.7
Potatoes	32.4	41.3	45.2	47.9	50.9	53.6	55.3	56.7
Onions	60.3	58.9	57.5	56.0	55.7	55.5	55.2	54.8
GEWC								
Citrus	32.0	36.4	37.1	36.7	37.8	38.7	38.9	38.9
Apples	21.8	32.6	37.3	40.1	44.2	47.9	50.2	51.7
Wine and Table grapes	10.5	13.4	14.4	14.7	15.6	16.3	16.7	16.9
Stone fruit	13.7	16.3	16.9	16.9	17.6	18.2	18.4	18.5
Pears	21.1	30.0	33.5	35.5	38.6	41.4	43.0	44.1
Wheat	2.0	2.4	2.6	2.8	3.0	3.1	3.2	3.3
Canola	1.0	1.2	1.4	1.5	1.6	1.6	1.7	1.8
Barley	1.7	2.6	3.0	3.5	3.9	4.2	4.5	4.7
Potatoes	32.4	41.3	45.2	47.5	50.1	52.3	53.6	54.4
Onions	60.3	58.9	57.5	55.6	54.8	54.2	53.4	52.6
GERC								
Citrus	32.0	36.4	37.1	36.8	38.0	39.1	39.4	39.6
Apples	21.8	32.6	37.3	40.2	44.5	48.3	50.8	52.6
Wine and Table grapes	10.5	13.4	14.4	14.7	15.7	16.5	16.9	17.2
Stone fruit	13.7	16.3	16.9	16.9	17.7	18.3	18.6	18.8
Pears	21.1	30.0	33.5	35.6	38.8	41.8	43.5	44.8
Wheat	2.0	2.4	2.6	2.8	3.0	3.1	3.3	3.4
Canola	1.0	1.2	1.4	1.5	1.6	1.7	1.7	1.8
Barley	1.7	2.6	3.0	3.5	3.9	4.3	4.6	4.8
Potatoes	32.4	41.3	45.2	47.7	50.4	52.7	54.2	55.2
Onions	60.3	58.9	57.5	55.7	55.2	54.7	54.0	53.4
GEBC								
Citrus	32.0	36.4	37.1	37.1	38.6	40.0	40.7	41.1
Apples	21.8	32.6	37.3	40.6	45.2	49.4	52.4	54.6
Wine and Table grapes	10.5	13.4	14.4	14.8	15.9	16.9	17.5	17.9
Stone fruit	13.7	16.3	16.9	17.1	18.0	18.8	19.2	19.5
Pears	21.1	30.0	33.5	35.9	39.4	42.7	44.9	46.5
Wheat	2.0	2.4	2.6	2.8	3.0	3.2	3.4	3.5
Canola	1.0	1.2	1.4	1.5	1.6	1.7	1.8	1.9
Barley	1.7	2.6	3.0	3.5	3.9	4.4	4.7	5.0
Potatoes	32.4	41.3	45.2	48.0	51.2	54.0	55.9	57.4
Onions	60.3	58.9	57.5	56.1	56.0	56.0	55.7	55.5

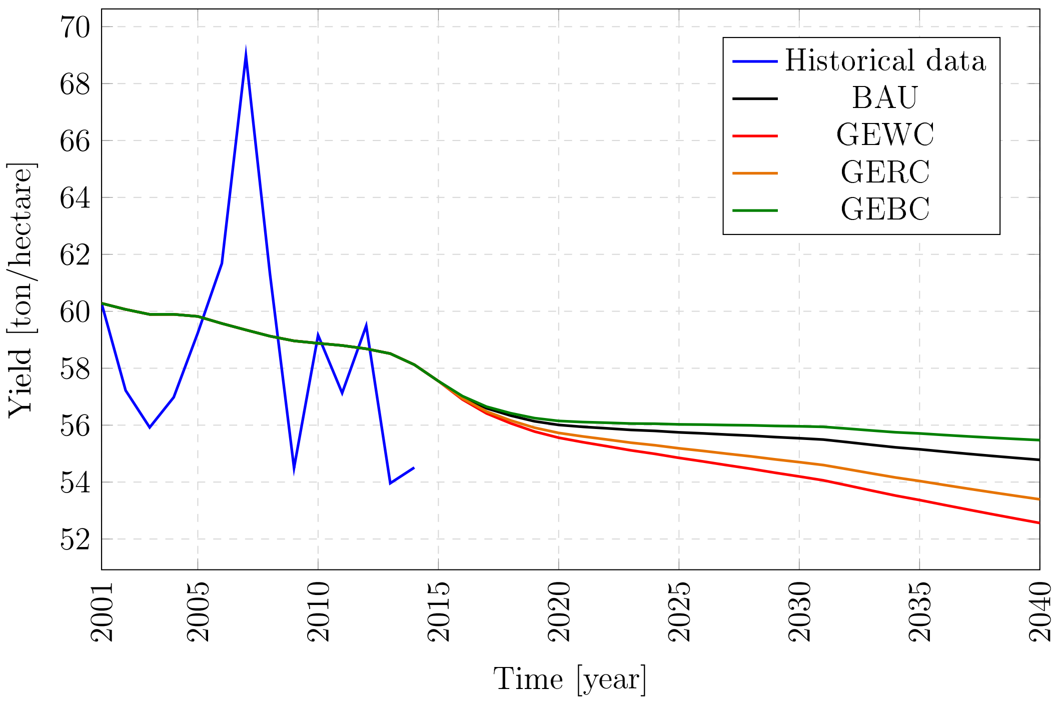

Figure 4.2: The projected onion yield for the Western Cape.

The BAU scenario indicates growth in yield per hectare for all the commodities expect for *onions* (see Table 4.2). Steady growth occurs (except for onions) over the simulation time frame and yields appear to reach a plateau in the latter stages on the simulation run. The growth in yield per hectare can be explained by an increase in agriculture capital. This increase in capital allows better farming technologies to be used when food crops are being produced and results in an increase yield per hectare. The diminishing yield per hectare for onions could be explained by climate change that is already affecting yield and that technological advancements cannot overcome this. Figure 4.2 illustrates onion yield for the four different scenarios and reveals its decreasing yields despite capital investment.

The GEWC scenario is projected to have the lowest yields as compared to the other scenarios by 2040, and this is as expected (see Table 4.2). This is a result of organic yield per hectare being set at 65% of conventional yield. Yields start to decrease after 2015, since this is when model policies initiate more food crops to be produced with sustainable farming techniques. Commodities categorised as vegetables and fruit experience decreasing yields for this scenario. Grains, however, experience similar yields for GEWC when compared to BAU. This is mainly due to area under conservation farming (40%) being more that the area under organic farming (15%) for grains, therefore, compensating for organic farming's shortcomings.

GERC yields per hectare are also lower than those of BAU (except for grains), but higher than GEWC. Here, conservation farming again helps grains to compensate for organic farming's diminishing yields. Organic yields did improve to 75%, but since 15% of all the seven other commodities are produced with organic farming, the yields still decrease when comparison is drawn with BAU.

The GEBC scenario has the highest yield per hectare for the ten different commodities. The assumption that organic yield could be exactly the same as conventional yield is the contributing factor in this scenario. This allows GEBC to have even higher yields than BAU by 2040, since organic yields were set as 75% with BAU. Refer to Appendix C for more yield results on an individual commodity level.

4.4 Food production

The effect that these changing commodity yields have on food crop production can now be analysed. Figure 4.3 depicts the change in total food crop production graphically. Appendix D can be consulted for food crop production results on an individual commodity basis.

The BAU scenario indicates a gradual increase in the total amount of food crops produced in the Western Cape until 2040. The total amount produced starts at 3.7 million tonnes in 2001 and production increases to 5.8 millions tonnes by 2040. The behaviour of the BAU follows that of historical data, and that is of a growing nature.

As observed from Figure 4.3, the three green economy scenarios follow the BAU behaviour closely. GRBC's production is slightly lower than BAU (-0.18%), whereas GEWC production is slightly more (0.31%) than BAU. These differences are however negligible, and food crop production for all four scenarios can be considered to be the same. Appendix D has the production results for each commodity.

The fact that food crop production is similar for all four different scenarios can be explained by the dynamics for the system structure. For example, if there is an excess in food crops, then price will decrease. This decrease in price will then result in farmers producing less and consumers increasing demand due to lower prices. Prices will then increase due to higher demand, and farmers will plant more which effectively again will result in a price decrease. This type of model behaviour creates an equilibrium and results in production being the same for the four different scenarios. The main variable that is affected by yield changes is land use since production needs to be met with changing yield per hectare and, therefore, results in land usage changes.

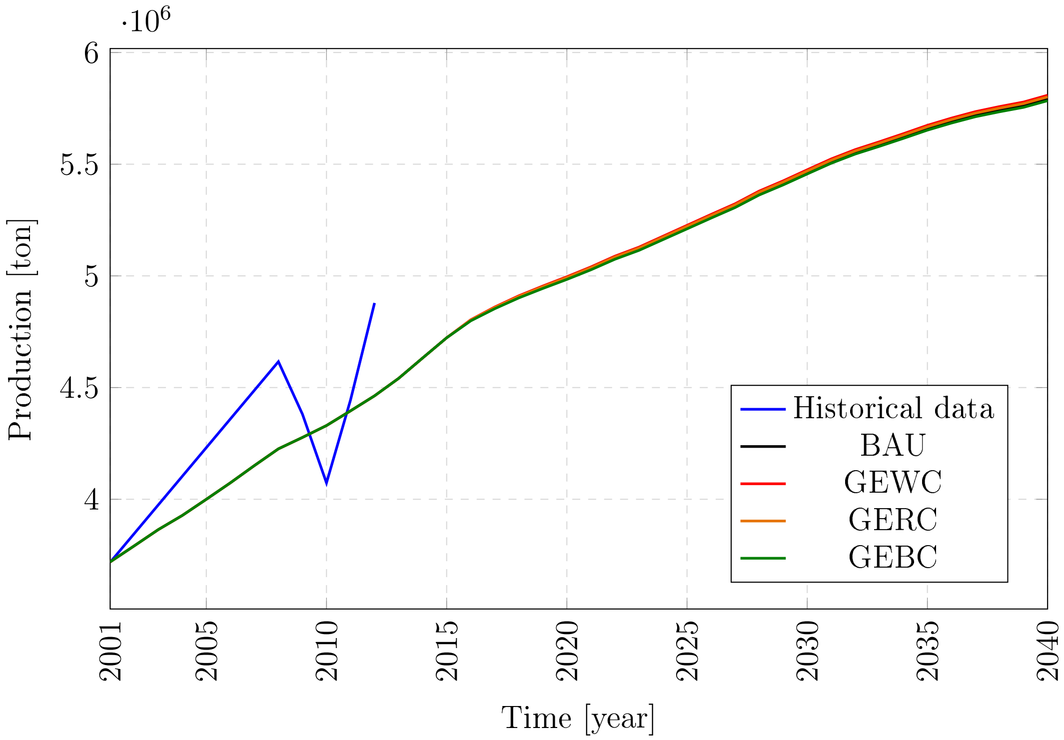

Figure 4.3: Total food crop production projected for the Western Cape.

4.5 Land required

Land required for food crop production is another important variable that needs to be analysed. The Western Cape is constrained by the amount of land it has available that can be used for all its practices. The simulation results show that the Province will never exceed its arable land when producing only these ten commodities. It needs to be noted that these ten commodities aren't the only entities that require arable land, there are other minor food commodities and livestock that also require arable land. Figure 4.4 illustrates the total land required for each of the four scenarios in order to achieve the production volumes discussed in Section 4.4.

All four model scenarios follow a general decreasing trend and the reason for this is due to change in yield per hectare. As noted in Section 4.3, agricultural capital increases over time and results in an increase in yield. This increase in yield, in turn, results in less area (or land) required to produce the same volume of food crops, and causes the land used for production to decrease as yield increases.

The BAU and GERC scenarios have the same land usage according to the simulation model. They are exactly the same and, therefore, GERC overlaps with BAU in Figure 4.4. For both these scenarios land usage decreases from

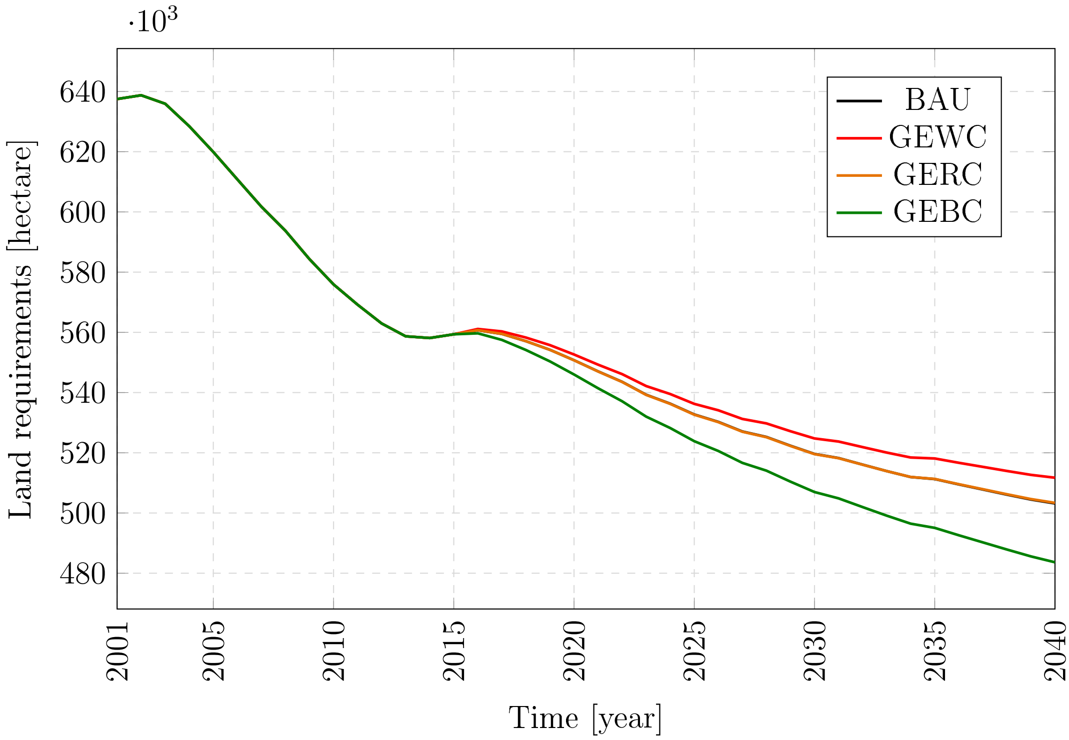

Figure 4.4: Total land requirements for the Western Cape's food crop production sector.

637 500 hectares in 2001 to 503 400 hectares in 2040, which represents a 21% decrease from 2001.

The GEWC scenario requires the most arable land to produce food crops. GEWC has the lowest yields per hectare of all the scenarios, therefore, it is expected that it would require the most amount of land. For this scenario, land usage decreases from 637 500 hectares in 2001 to 511 700 hectares in 2040. This is, however, 8 300 hectares more than with either BAU or GERC.

GEBC displayed positive results in that the land required for this scenario was notability less than for any of the other three scenarios. Land usage decreased from 637 500 hectares in 2001 to 483 600 hectares in 2040, which represents a 24% decrease. This is also 4% less in 2040 when compared to BAU and GERC, and 5% less than GEWC. This could also have significant benefits for GEBC with regard to GHG emissions which is discussed in Section 4.7. For land usage results on an individual bases, Appendix E can be consulted.

Table 4.3: A summary of the scenarios' price results for the different commodities ($Rand/ton$).

Commodity	**Time**							
	2001	2010	2015	2020	2025	2030	2035	2040
BAU								
Citrus	1546	2879	4408	4721	6335	8948	11585	13676
Apples	1907	4100	5758	7038	8899	10948	12624	14111
Wine and Table grapes	4410	7538	8872	10018	11111	12217	12865	13143
Stone fruit	5322	7754	10355	12532	15172	18361	20944	22745
Pears	2203	5214	7395	8869	11170	13759	15966	17744
Wheat	1422	2279	2913	3522	4153	4819	5178	5378
Canola	1638	3891	5185	6380	7463	8452	9251	9807
Barley	1000	2377	3051	3621	4100	4515	4827	5021
Potatoes	1179	2259	2989	3653	4381	5155	5706	6128
Onions	1192	2808	3345	3885	4335	4749	5044	5245
GEWC								
Citrus	1546	2879	4408	4578	5838	7796	9530	10617
Apples	1907	4100	5758	6967	8714	10603	12090	13362
Wine and Table grapes	4410	7538	8872	10012	11095	12188	12822	13085
Stone fruit	5322	7754	10355	12474	14978	17962	20299	21836
Pears	2203	5214	7395	8770	10890	13224	15124	16564
Wheat	1422	2279	2913	3522	4152	4816	5175	5373
Canola	1638	3891	5185	6379	7461	8449	9245	9798
Barley	1000	2377	3051	3621	4100	4515	4825	5020
Potatoes	1179	2259	2989	3634	4328	5057	5557	5924
Onions	1192	2808	3345	3902	4391	4854	5205	5465
GERC								
Citrus	1546	2879	4408	4631	6020	8211	10259	11685
Apples	1907	4100	5758	6993	8783	10732	12290	13642
Wine and Table grapes	4410	7538	8872	10014	11101	12199	12838	13107
Stone fruit	5322	7754	10355	12496	15050	18111	20541	22176
Pears	2203	5214	7395	8807	10994	13424	15438	17003
Wheat	1422	2279	2913	3525	4160	4832	5197	5403
Canola	1638	3891	5185	6382	7470	8468	9279	9847
Barley	1000	2377	3051	3621	4101	4519	4832	5029
Potatoes	1179	2259	2989	3641	4348	5094	5613	6001
Onions	1192	2808	3345	3896	4370	4814	5144	5380
GEBC								
Citrus	1546	2879	4408	4766	6499	9339	12303	14780
Apples	1907	4100	5758	7060	8957	11057	12792	14348
Wine and Table grapes	4410	7538	8872	10019	11116	12226	12879	13160
Stone fruit	5322	7754	10355	12550	15232	18485	21147	23030
Pears	2203	5214	7395	8900	11258	13929	16233	18120
Wheat	1422	2279	2913	3532	4181	4869	5253	5476
Canola	1638	3891	5185	6387	7493	8517	9361	9967
Barley	1000	2377	3051	3623	4106	4528	4848	5051
Potatoes	1179	2259	2989	3659	4397	5186	5752	6192
Onions	1192	2808	3345	3880	4318	4717	4996	5180

4.6 Food price

Food crop price is affected by multiple role-players in the real system and in the simulation model. If population increases then demand increases and the food crop price increases for that specific commodity. If food crop production increase then food crop price decreases since the demand/supply ratio decreases. The food crop price itself also affects consumers and producers. If the price increases, then consumers tend to buy less or look for alternatives, resulting in reduced demand. If price increases, then producers (or farmers) seek to exploit the financial opportunity and increase planned production.

The food crop price results, of the described system behaviour above, for the four different scenarios are represented in Table 4.3. For all four scenarios, the food crop price for the ten different commodities experience steady growth from 2001 until 2040. If the food crop price of grains (wheat, canola, and barley) for 2040 are observed for the four different scenarios, a remark can be made that they remain almost similar for each scenario (see Table 4.3). This is a consequence of their production being similar for each scenario and the demand remaining the same throughout the simulation. Vegetables' prices also remains similar for the four scenarios, with the price differences being negligibly small at 2040.

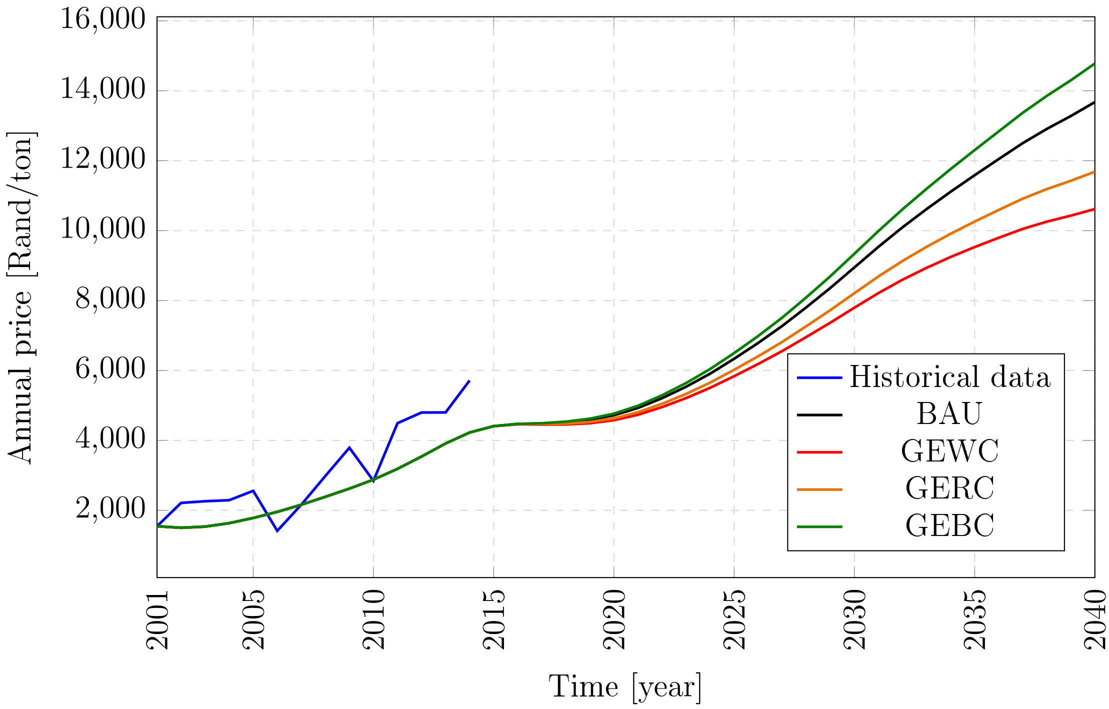

Figure 4.5: The food price for citrus fruit with the four different scenarios.

For most fruits, the price difference between the green economy scenarios (GEWC, GERC, and GEBC) when compared to BAU are also negligibly small (less than 5%). Citrus fruit is the only exception to this price difference and Figure 4.5 is a graphical representation of citrus price for the different scenarios. The GEBC scenario produced marginally less citrus fruit from 2015 onward. This then results in an increase of R1 103.00 per ton (7%) in the food price as compared to BAU in 2040. The citrus price decreases significantly for both GEWC and GERC scenarios when examined to BAU. The GEWC citrus price experiences a decrease of R3 059.00 per ton (29%) when compared to BAU price, whereas GERC price decreases by R1 991.00 per ton (17%) when compared to BAU price in 2040.

The above mentioned results highlight the sensitivity of the model with regard to citrus food crop production. Farmers are sensitive to yield changes and, therefore, over produce with low yield conditions, and under produce with higher yield conditions. This explains the higher food price for citrus with higher yields (due to lower production) and the lower food price with low yields (due to over production). Appendix F has the results of price for each of the ten different commodities.

4.7 Emissions from food crop production

Emissions sanctions is a potential problem that South Africa faces and the emission of the country as a whole needs to decrease. It was also highlighted that the Western Cape government's aim for agriculture is to adopt more sustainable farming practices. In light of this, the emissions produced by food crop production is considered to be a crucial model output. Figure 4.6 represents the emissions created by producing food crops for the four different scenarios.

The first notable remark is that the trend of the emissions is similar to that of land used for food crop production (see Figure 4.4). Emissions follow the same trend as land used, due to the way the model is built. Emissions from food crop production is calculated by determining the emission per hectare for the different commodities and farming practices, and that creates this close resemblance between Figure 4.4 and Figure 4.6.

In general, all four scenarios GHG emissions decrease over the simulated time. This is a result of increasing yield, which affects land requirements. As noted in Section 4.5, yield increases due to an increase in capital investment and, therefore, less land is required to produce food crops.

As expected, the GEBC scenario emits the least amount of GHG emissions of the four scenarios. GEBC's emissions start at 2.75 million tonnes of CO_2 in 2001 and decrease to 2.24 million tonnes of CO_2 by 2040. This represents a 19% decrease from initial emissions. The GEBC scenario also emits 6% less GHG emissions than the BAU scenario by 2040. GEBC superior organic

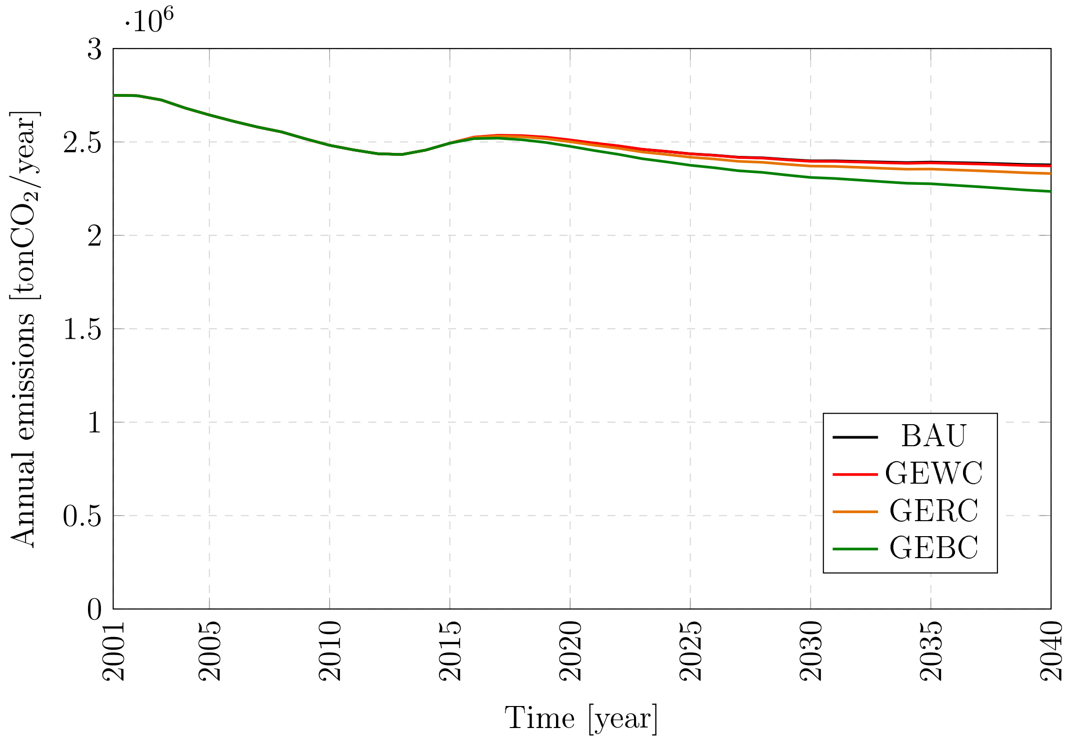

Figure 4.6: Annual GHG emissions created from total food crop production in the Western Cape.

yield (100% vs. conventional) results in less land required to produce food crops, and, therefore, has the lowest amount of GHG emissions. GEBC's emissions start to decrease more rapidly than BAU in 2015 when organic and conservation farming practices are more significantly employed.

GERC is the second best scenario when GHG emissions are considered. As previously noted, all four scenarios have decreasing emissions, including GERC. GERC's initial emissions are the same as GEBC and decrease to 2.33 million tonnes CO_2 by 2040. GERC emits less GHG emissions than both GEWC and BAU, and is 2% less than BAU by 2040.

GEWC and BAU achieved similar results when their GHG emissions are compared (see Figure 4.6). The difference between the two scenarios is so small that they can be considered to be equal. BAU was expected to be the highest GHG emitter, but GEWC was never expected to be the same as BAU. GEWC unexpected poor results with regard to GHG emissions can, however, be explained if its organic yield is examined. Its organic yield was set at 65% of conventional yield, and therefore required more agricultural land to produce food crops than BAU, GERC, and GEBC. The amount of GHG emissions saved per hectare for GEWC is, however, not enough to offset the additional land requirements, and therefore, GEWC has similar GHG emissions to BAU.

For both scenarios GHG emissions start at 2.75 million tonnes CO_2 in 2001 and decrease to 2.38 million tonnes of CO_2 by 2040.

4.8 Green economy investment

The last important model output is the green economy investment expenditure. As described in Section 3.4.8, this is the additional cost required for the different modelling scenarios when sustainable farming practices are used. Simulation results for green economy investment by the four scenarios is graphically represented in Figure 4.7. Figure 4.7 represents the accumulated required green economy investment until each given time point. All four scenarios only start to require investment from 2015, and the reason for this is that sustainable farming practices are assumed to only start in 2015.

As expected, the BAU scenario requires the least amount of financial investment. This scenario has the least amount of food crops being produced by sustainable farming practices, therefore, its financial requirements are the lowest. By 2040, the total cost of the BAU scenario is projected to be R972.3 million (see Figure 4.7).

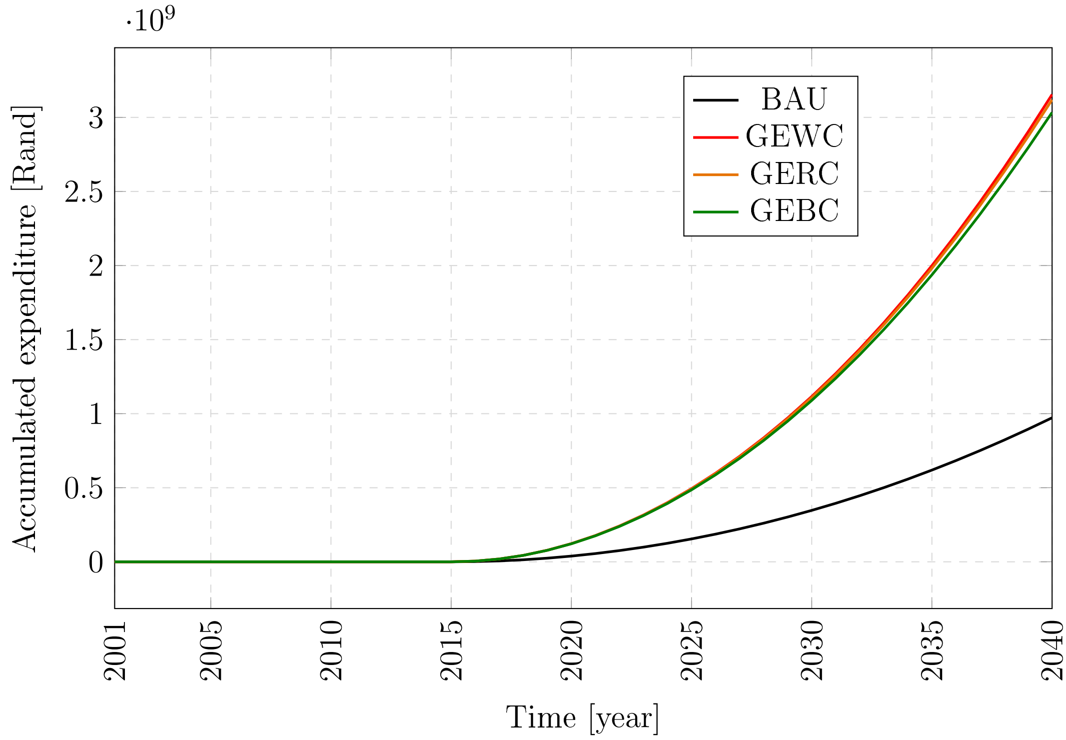

Figure 4.7: Accumulated investment required for each of the four different scenarios.

The three green economy scenarios have similar cost as depicted by Figure 4.7. These three scenarios require significant financial investment when compared to BAU and this can be attributed to the food crop area increase under sustainable farming practices. The GEWC scenario requires the biggest investment of the three green economy scenarios, followed by GERC and GEBC. The difference in investment between these three scenarios can be explained by the difference is land requirements between them. As remarked in Section 4.5, GEWC requires the most amount of land, followed by GERC, then GEBC. GEWC requires a total investment of R3.16 billion by 2040, which represents a 225% increase when compared to BAU investment costs. GERC and GEBC require R3.12 billion and R3.03 billion by 2040 respectively. The GERC and GEBC scenarios represent an increase of 221% and 212% when compared to BAU investment costs respectively.

4.9 Conclusion: Modelling outcomes

This chapter quantified the four scenarios' input parameters and discussed the model findings of key output variables. The findings highlighted the growth of the population of the Western Cape to 7.8 million people by 2040. Yield per hectare also increases for all four scenarios. These increases in yield results in less land being used to produce food crops. Food crop production remains similar for all four scenarios, and shows steady growth. Food price was only marginally affected by the different scenarios and also shows steady growth until 2040. Table 4.4 summarises the most important simulated scenario results. Emissions are decreasing from 2001 to 2040 according to the model findings, with GEBC achieving the best results in terms of emissions and agricultural land required. The GEBC scenario also require the least amount of financial investment when compared to the other two green economy scenarios. All three green economy scenarios require significant financial investment when compared to BAU.

The last chapter of this study discusses the modelling outcomes, where recommendations are made to stakeholders based on these model findings. The limitations and future improvements of the model are also discussed.

Table 4.4: A summary of simulated scenario results by 2040.

Scenario	Annual CO_2 emissions (million ton CO_2)	% Change vs. BAU	Land required (hectare)	% Change vs. BAU	Total Financial Investment (R million)	% Change vs. BAU
BAU	2.38	0%	503 400	0%	972.3	0%
GEWC	2.38	0%	511 700	2%	3 160	225%
GERC	2.33	-2%	503 400	0%	3 120	221%
GEBC	2.24	-6%	483 600	-4%	3 030	212%

Chapter 5

Study Conclusions and Recommendations

Chapter 4 discussed the different results obtained from the model for the four modelling scenarios and different model outputs. The green economy best case (GEBC) scenario offered the best solution in terms of GHG emissions, with the organic yields being optimistic. The business as usual (BAU) scenario predicted the results of current practices. The model results highlighted the significant financial investment required for the transition to green economy within food crop production.

This chapter provides a conclusion to the research as a whole. It aims to provide an answer or solution to the research objective stated in Section 1.3 and make recommendations based on the findings. Stakeholders and policy makers can use these recommendations as a guideline to better manage the transition to a green economy within the food crop production sector of the Western Cape.

This chapter firstly highlights import findings for each scenario from Chapter 4. This chapter provides recommendations, where the scenario results are interpreted. The limitations of the model and model boundaries are also highlighted. These limitations also provide solutions to proposed ideas to improve the model for future research and scenario analysis.

5.1 Important findings

Important model findings were made in the previous chapter and they will be briefly summarised in the next section, before recommendations are made in the following section. There are four different modelling scenarios (BAU, GEWC, GERC and GEBC) as previously described in Section 3.6. The detailed results of different model outputs for these four scenarios are discussed in Chapter 4.

5.1.1 Business as usual findings

The behaviour of the BAU scenario results is what was expected. The population of the Western Cape experiences steady growth until 2040. This growing population results in an increase in food crop demand for the 10 different food crop commodities. This behaviour was as expected. All 10 different commodities experience a significant increase in yield (except for onions) by 2040. This can be explained by the increase in capital investment in agriculture, which allows for better technologies to be used to produce food crops. As noted in Section 4.3, the diminishing yield per hectare for onions could be explained by climate change that is already affecting yield and that technology advances cannot compensate for this.

The volume of food crop production also increases steadily, as it attempts to meet demand requirements of the Western Cape, the rest of South Africa, and global exports. As with yield, the food crop price also increase significantly over the simulated period. As land requirements decrease for this scenario (due to improved yields), GHG emissions also decrease. The financial investment for this scenario is also considerably less when compared to GEWC, GERC and GEBC. This can be explained by less sustainable farming practices being adopted for this scenario.

5.1.2 Green economy worst case findings

The GEWC scenario was defined as a pessimistic view with regard to organic yields as described in Section 3.6. For this scenario, organic yields were set to 65% of that on conventional yields. Most of the scenario's behaviour was as expected. The predicted population is the same as with BAU. The yields for the 10 different commodities were notably less by 2040 when compared to BAU, and this was again as expected due to lower organic yield and the fact that organic practices were more widely used. Grain yields remained almost exactly the same as for BAU, and this is a result of conservation farming compensating for organic yield losses.

Food crop production was only marginally more than that of BAU. Model behaviour attempts to meet demand and, therefore, production volume is almost the same as with BAU. The noticeable difference arises with land used to produce food crops. Due to lower yields, GEWC requires more land than BAU and is the scenario that requires the most land. Again this was as expected and with this increase in land requirements, it is expected that this scenario will emit the most GHG emissions of the three different green economy scenarios. What was not expected is that the GEWC scenario would emit almost exactly the same amount of GHG emissions as BAU. Since this is a green scenario the financial investment required is significant and almost three times that of BAU.

5.1.3 Green economy realistic case findings

For the GERC scenario a realistic view was taken with regards to organic yield and it was chosen as 75% of that of conventional yield for the different food crop commodities. The different food crop yields for the GERC scenario are projected to be lower than those of BAU, but higher than GEWC. This improved yield is expected to have more positive results than GEWC.

Although the volume of food crop production remains similar for GERC when comparison is drawn to BAU and GEWC, it requires less land to produce these food crops than with GEWC. Land requirements are similar to that of the BAU scenario. The emissions for this scenario were, however, not similar to those BAU scenario's GHG emissions, they were significantly lower. This can be explained by the increase in sustainable farming practices even though the same area of land is required.

This scenario also requires significant financial investment when related to BAU. The required investment is similar to that of the GEWC scenario, but only marginally less seeing that less land is required to produce the same volume of food crops.

5.1.4 Green economy best case findings

The last scenario is GEBC and has a optimistic view on organic yield. Organic yield is set at 100% of conventional yield for this scenario. For this scenario, food crop yields were predicted to be slightly more when compared to BAU. As noted in Section 4.3, this is due to organic yields being set at 75% for BAU. The volume of food crops produced remained similar to the other three scenarios.

This increase in yield has a positive effect on land requirements for the GEBC scenario. This scenario requires the least amount of land to produce the required food crops of the four scenarios. This leads to GEBC also emitting the least amount GHG emissions. When its financial investment costs are compared to that of GEWC and GERC, it costs marginally less. This is primarily due to the difference in land requirements. This scenario is evaluated to be the best outcome of the three green scenarios.

5.2 Recommendations to stakeholders

The study objective, as described in Section 1.3, was to provide stakeholders with support in order to better manage this transition within the agricultural food crop production sector for the Western Cape. The model helped to gain a better understanding of the implications of this green economy transition, and through scenario testing, identify certain areas that can be targeted to help this transition.

There are three areas that can be targeted to assist the green economy transition, namely financial costs, organic yields, and conservation farming. As highlighted in the previous section, financial cost is a key area of concern for the three green scenarios due to the severity of the cost. The three green scenarios also tested the organic yield impacts on food crop production where organic yield improvements are considered another option. Promoting conservation farming is the last targeted area to help stakeholders with the green economy transition with food crop production.

5.2.1 Recommendation 1: Financial cost

As highlighted in Section 4.8, the green economy will require significant financial investment. It is projected to have a total cost in excess of R3 billion in current monetary worth by 2040. This represents the first major challenge for the transition to a green economy within the agricultural food crop production sector of the Western Cape.

An argument can be formed that farmers would fund the required financial investment due to organic food crops having a higher market value than conventional food crops. The model, however, assumes that food crops are produced organically in order to be more sustainable, rather than catering for niche market where organic food crops cannot be afforded by the majority of the province's citizens due to higher prices. This means that farmers will not receive a superior food price which would be used to pay the extra financial cost.

Fruits require an extra cost of R8 000.00 per hectare to be produced organically, while grains require more than R1 600.00 per hectare. The additional cost associated to produce potatoes organically is R8 100.00 per hectare while onions require an additional R40 000.00 per hectare. It, therefore, seems highly unlikely that farmers would fund these cost if there is no significant benefit to them.

A possible solution is that the Western Cape's government provides subsidies to farmers that implement organic farming practices for these 10 different commodities. This requires the local government to fund the projected R3 billion investment cost itself. If either GEWC and GERC is the case, in terms of organic yield, then this financial investment will not be worthwhile if emissions is the main criteria. GEBC emits 6% less GHG emissions by 2040 than BAU (see Section 4.7), and could be viewed as worth the financial cost for government. GEBC's GHG emission reduction could be even more if the organic yields can be improved, which would result in more food crops being produced with organic practices since it would potentially be higher than conventional practices.

5.2.2 Recommendation 2: Organic yield improvements

The three green economy scenarios tested the uncertainty surrounding organic yields when compared to their conventional equivalent. GEWC and GERC both highlighted that if organic yields are less than conventional yields, then the GHG emissions will not decrease enough to justify the financial investment required. Both de Ponti *et al.* (2012) and Tuomisto *et al.* (2012) noted that the average yield for organic food crops are 75% in the two independent studies.

Both studies were conducted in Europe and there is a lack of research about organic food crop yields in South Africa, and the Western Cape specifically. To increase the model's accuracy, it is recommended that more research be done with regard to organic yields in the Western Cape specifically. This will also have the added benefit of convincing farmers to adopt organic farming practices because they will be more likely to consider findings that are more relevant to them. GEBC highlighted the advantage of organic farming when it has similar yields to that of conventional farming. It is, therefore, also recommended that more funding be provided to agricultural research in order to help improve organic yields for the Western Cape specifically.

If yields cannot be improved through research, then perhaps organic regulations should be changed in order to accelerate the transition from conventional farming practices to those of organic. Humans are notorious for resisting change and the regulations with regard to organic farming could potentially prove to be a stumbling block. By slacking organic regulations initially and then gradually increasing them, more farmers could potentially adopt organic farming. Farmers could also potentially use this gradual increase in regulations to their advantage and find potential solutions to improve organic yield without government funding and research.

If an initial compromise cannot be found and organic regulations are not allowed to change, then genetically modified crops (GMCs) could also be considered for organic farming. Although this recommendation might be highly controversial, it provides a reasonable solution. Organic regulations limit the use of pesticides and other chemicals, therefore, organic yields struggle to compete with conventional yields. GMCs overcome this by being modified to be more resistant to pests etc.

5.2.3 Recommendation 3: Conservation farming promotion

Conservation (or no-till) farming practices is where soil disturbance is reduced to a minimum according to Venter (2015). Organic matter is left on the production area and accumulates in the soil. Conservation farming has multiple advantages, yet conventional farming practices remain popular in the production of grains in the Western Cape.

Venter (2015) highlights six advantages when using no-till farming practices to produce food crops. The first major advantage of no-till is that it helps to reduce soil erosion. The second advantage is that water and moisture in conserved and, therefore, helps to reduce drought stress. This is a big positive in terms of the uncertainty of the impact of climate change on the province's water stress levels. He also notes that evaporation from the soil is reduced by 75%. Reduction in machinery cost and labour savings are the fourth and fifth advantages of no-till, according to Venter (2015). The last advantage of no-till farming practices is yield improvements of up to 33% in the Western Cape.

A study by Lankoski *et al.* (2006), that compared conventional farming to no-till farming, found that no-till farming cost close to 49 euros/ha (or currently R661.00/hectare) less than conventional farming. This only adds to the growing list of no-till advantages when compared to conventional farming.

In light of the overwhelming advantages for conservation farming practices, it is recommended that the Western Cape's government promote conservation farming among grain farmers in the province. They should highlight the above mentioned advantages and conduct further research into any issues farmers have doubts about.

5.3 Model limitations

This section includes the model limitations in terms of system behaviour and other variables not considered during model development that could potentially increase model accuracy. Some were omitted due to time constraints and research scope while others were omitted due to modelling difficultly.

The first limitation of the model is the different food crop prices themselves. Most food crops have different grades that influence their market prices. The model assumed that all the food crops produced for each commodity was of the highest grade and, therefore, fetches premium prices.

Organic food crops are also assumed to cost the same as conventional food crops. Organic food crops generally cater for a niche market and, therefore, cost significantly more than conventional crops. The reason for this argument is that the Western Cape is a third world "country", and its citizens will not be able to afford premium niche food prices. Organic farming is viewed as a solution to sustainable farming practices, rather than a way for farmers who cater for a niche market for self-enrichment.

The different food crop commodity prices are assumed to only be influenced by local demand (Western Cape and the rest of South Africa), exports and supply. World prices for different food crops have an impact on local food crop prices. Due to the difficulty in modelling the rand/dollar exchange (this will need to be adapted to become Western Cape's "rand") and predicting the world prices themselves, the world food crop prices do not form part of this model.

Another model limitation is that food crop production does not affect the Western Cape's GDP. The GDP per capita affects population in terms of death rate. The GDP, however, remains unaffected by the different scenarios in this model, and results in the Western Cape population being unaffected for the different scenarios.

The demand for food crops in the Western Cape and the rest of South Africa is assumed to only be for that of the human population. There is no livestock model, for the Western Cape, that could be integrated with this model that predicts the food crop demands for different livestock populations within the province. The same is applicable to the rest of South Africa. Due to time constraints, a livestock population and demand module was not considered for this model.

The yield of each food crop commodity's accuracy could be improved by including employment in the model, and having employment affect yield per hectare. This is another limitation of the model and should be considered for future research work. The different food crop yields were also aggregated to a provincial view and this also potentially limits the accuracy of model findings. The model could be broken up into the six different districts to improve model accuracy. It will, however, be difficult to acquire district specific data.

The only aspect of climate change that affects food crop yield is that of water stress. Temperature change did not form part of the model and could potentially also affect food crop yields. The water stress for the model was assumed to be that of South Africa, which was obtained from South African Green Economy Model (SAGEM) (UNEP, 2013*b*; Musango *et al.*, 2014). Currently, there is no functioning water model that predicts water stress for the Western Cape itself, so the South African water stress was used and limits the accuracy of the model.

5.4 Suggested future research

The section discusses future research that has been identified during the study. This could either be model improvements or other sectors that could be modelled. Modelling the green economy of other provinces is also recommended in this section.

This study forms part of a research project that aims to model the whole Western Cape and how a transition to green economy would affect different sectors. Sectors that are currently being model include: food crop production, transport infrastructure, biofuels, the energy sector, and the water sector. Livestock and the industry sector were excluded from the research. By modelling the impact a green economy transition has on these additional sectors, the implications the green economy transition has for the Western Cape can be better understood.

The research is also only focussed on the Western Cape specifically. The only other green economy model that relates to South Africa is SAGEM. The bigger Western Cape model attempts to provide a better understanding of the implication of green economy transition in the province, considering the lack of knowledge and literature available about these implications for the Western Cape province. Future research could potential focus at building green economy models for the other eight provinces of South Africa, namely:

- Northern Cape,
- Eastern Cape,
- Free State,
- North West Province,
- Kwazulu Natal,
- Mpumalanga
- Gauteng, and
- Limpopo.

This would help to decrease the lack of literature and knowledge surrounding the implications of a green economy transition in the other provinces. If there is a green economy model for each of the nine provinces of South Africa, then they could be integrated to influence each other and even replace SAGEM. This would allow for an even more accurate South African green economy model.

A recent suggestion is that organic yields improve over time, and therefore start significantly lower than conventional yields and gradually improve. Consequently, another suggestion for future research would be to model this behaviour and create a "worse before better" model scenario.

As previously mentioned this study forms part of a greater research effort to better understand the implications of a green economy transition within the Western Cape Province. When the different models are completed and integrated, it is recommended that the different sectors (agriculture, biofuels, energy, water and infrastructure) are evaluated according to cost per ton of CO_2 avoided. This would help to identify the preferred sectors for green investment.

The last recommendation for future research is to improve on the model by addressing the limitations described in the previous section (Section 5.3). Improving the model to allow employment to affect yield is one of the suggestions in the previous section. The impact of climate change (excluding water stress) is another suggestion worth noting. In general any improvement on the model limitations would be of value to future research.

5.5 Research reflection

Insightful lessons were learnt while conducting this study and this section aims to communicate some of the most notable lessons. This section also allows for a reflection on the research process and methodology and provides recommendations to future researchers who might consider SDM for similar research. The last part of this section discusses noteworthy findings that were made about the lack of research and communication in the food crop production sector of the Western Cape.

5.5.1 Usefulness of SDM

System dynamics provides a sufficient way of better understanding the implications of the transition to green economy has on food crop production. The modelling approach is both simple yet complex when required. It is this complexity of the modelling method that can become time consuming. Most modelling methods categorise variables into different silos that interact independent of each other. System dynamics modelling however brings these silos together to create a more complex and realistic model. If the problem is simple or aggregated enough, then system dynamics modelling might not be the recommended approach to better understand the problem.

Understanding and getting to grips with the software can be troublesome. Vensim caters for most modelling needs in terms of what is required for system dynamics modelling. It is a bit overwhelming initially, but becomes more familiar as more time is spent using and modelling with the software. Any potential model developer needs to consider the steep learning curve when considering system dynamics modelling and Vensim.

If the problem at hand is simple then a different modelling approach could be used. Microsoft Excel could also be used while applying SDM principles, if the problem is simple. Modelling the problem is not the only option either. Performing case studies can also provide valuable insights into the behaviour of systems. By better understanding a system's behaviour, simple predictions can be made as to how the system will react to certain changes in its "environment". If there is not a significant time constraint, agent-based modelling should be reconsidered. An agent-based model would potentially yield more accurate results.

Many "soft" issues are conceptualised as being part of the CLD, but are more difficult to incorporate in the SFD. It might be known that some random variable affects another variable, but the mathematical relationship between the two might not be known. One could use historical data to calibrate these relationships, but historical data is not always easy to obtain. Here in lies another obstacle of SDM. Further more, if there is no quantitative research about specific soft issues, it becomes challenging to incorporate these soft issues into the SFD since qualitative relationship need to be converted to quantitative relationships. This then reduces the confidence model developers have in the model's behaviour.

SDM also struggles to simulate sporadic events. The is primarily due to SDM not being event based. SDM is best suited to problems associated with continuous processes. Simulating an economy is great example of a continuous process and highlights why SDM was ideal for this study.

The model developer also requires knowledge about multiple areas in order to build an accurate and valid SD model. By linking variables from different silos, the model developer needs to have sufficient knowledge of each silo. When verifying the model with stakeholders, they might highlight model behaviour flaws they were able to identify due to their specific knowledge in the silo "environment". The ideal approach would be to continually use stakeholders as part of the model building process. They would then have more confidence in model behaviour when stakeholders verify it, and the model developers do not require specific knowledge about the different silos "environments".

Regardless of the highlighted scepticism above, SDM is still considered as an appropriate way to better comprehend the implications a green economy transition has on food crop production in the Western Cape. Stakeholder engagement was sufficient enough to build a basic model and the model's complexity does not require significant knowledge in food crop production. If the accuracy of the model's food crop production were to be improved, and the model is adapted to each of the ten food crop commodities specifically, then additional stakeholder engagement is required for each commodity.

The SD model provides a useful "tool" that managers and stakeholders can use to experiment with model outputs, without changing model structure or requiring the model developer assistance. They can use their experiments to verify model behaviour and test new scenarios.

5.5.2 Noteworthy findings

There is a significant lack of knowledge and research in South Africa and the Western Cape with regard to the impacts of a green economy transition on food crop production. This became even more apparent as the study progressed. It, therefore, identifies the need for similar research. In order to better manage the green economy transition in the Western Cape, more research needs to be done.

Another useful lessons was that it became clear that sustainable farming is still a relative "new" idea in the Western Cape. Even though the concepts of organic and conservation farming have been around for some time, there is every little research available that is Western Cape specific. There are almost no agricultural studies available with regards to the organic farming in terms of yield, emissions, and cost per hectare for the province. Agricultural studies with regard to conservation farming have only been done for wheat, while canola and barley have so far been excluded.

There also appears to be dysfunctional communication between public and private organisations. The Department of Agriculture (DOA) has limited food crop production data, but it is expected that it should be the primary source of information with regard to food crops. Private organisations were consulted in order to acquire accurate historical production data for the Western Cape specifically.

5.6 Concluding remarks

Changing our current way of living and functioning has become more apparent as climate change begins to affect the world. In a country such as South Africa, where finances are both limited and poorly managed, it is vital that any green economy transition is managed as best as possible. System dynamics modelling helped to better understand the implications a green economy transition will have on the food crop production sector of the Western Cape. By gaining a better understanding of the impacts on food crop production, this study helped by starting to fill a "gap" in the literature. The study also lays the foundation for future research, and will hopefully contribute to the Western Cape becoming the lowest carbon province in South Africa and leading green hub on the African continent.

List of References

Abdou, M., Hamill, L. and Gilbert, N. (2012). Designing and building an agent-based model. In: *Agent-based models of geographical systems*, pp. 141–165. Springer.

Agri SA (2013). Annual report 2012/2013. Accessed on: 02 June 2014.
Available at: www.agrisa.co.za

Ahmad, S. and Simonovic, S.P. (2000). System dynamics modeling of reservoir operations for flood management. *Journal of Computing in Civil Engineering*, vol. 14, no. 3, pp. 190–198.

Albin, S. (1997). *Building a System Dynamics Model Part 1: Conceptualization*. Massachusetts Institute of Technology.

Albrecht, M. (2010). Introduction to discrete event simulation. Accessed on: 3 April 2014.
Available at: http://www.albrechts.com/mike/DES/index.html

Allen, M.J. (2014). What is "discrete-event simulation"? Accessed on: 3 April 2014.
Available at: http://facsim.org/Documentation/FAQ/SimulationFAQ/S1.html

Angerhofer, B.J. and Angelides, M.C. (2000). System dynamics modelling in supply chain management: research review. In: *Simulation Conference, 2000. Proceedings. Winter*, vol. 1, pp. 342–351. IEEE.

Antle, J.M. (2008). Climate change and agriculture: Economic impacts. Accessed on: 05 June 2014.
Available at: http://www.choicesmagazine.org/2008-1/theme/2008-1-03.htm

Babulak, E. and Wang, M. (2010). Discrete event simulation. *Aitor Goti (Hg.): Discrete Event Simulations. Rijeka, Kroatien: Sciyo*, pp. 1–9.

Balestrini-Robinson, S., Zentner, J.M. and Ender, T.R. (2009). On modeling and simulation methods for capturing emergent behaviors for systems of system. In: *12th Annual Systems Engineering Conference*. National Defense Industrial Association.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System dynamics review*, vol. 12, no. 3, pp. 183–210.

Bertsekas, D.P. (1998). *Network Optimization: Continuous and Discrete Models*. Athena Scientific, Belmont, Massachusetts.

Borshchev, A. and Filippov, A. (2004). From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. In: *Proceedings of the 22nd international conference of the system dynamics society*, vol. 22.

Brailsford, S. and Hilton, N. (2001). A comparison of discrete event simulation and system dynamics for modelling health care systems. In: *Proceedings of ORAHS 2000*. Glasgow Caledonian University.

Brown, D. (2014). Answers to destination confusion. western cape tourism regions. Available at: http://jabedi.com/tag/western-cape/

Castro, P.M., Aguirre, A.M., Zeballos, L.J. and Méndez, C.A. (2011). Hybrid mathematical programming discrete-event simulation approach for large-scale scheduling problems. *Industrial & Engineering Chemistry Research*, vol. 50, no. 18, pp. 10665–10680.

Coenen, L., Benneworth, P. and Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy*, vol. 41, no. 6, pp. 968–979.

Cronin, P., Ryan, F. and Coughlan, M. (2008). Undertaking a literature review: a step-by-step approach. *British Journal of Nursing*, vol. 17, no. 1, p. 38.

Crooks, A., Castle, C. and Batty, M. (2008). Key challenges in agent-based modelling for geo-spatial simulation. *Computers, Environment and Urban Systems*, vol. 32, no. 6, pp. 417–430.

Davies, R. (2006). Developing network models of development projects: An introduction. Accessed on: 04 May 2015.
Available at: http://www.mande.co.uk/networkmodels.htm#11._Examples_of_network_data_and

de Ponti, T., Rijk, B. and Van Ittersum, M.K. (2012). The crop yield gap between organic and conventional agriculture. *Agricultural Systems*, vol. 108, pp. 1–9.

De Wit, M. and Crookes, D.J. (2013). Improved decision-making on irrigation farming in arid zones using a system dynamics model. *South African Journal of Science*, vol. 109, no. 11-12, pp. 1–8.

Diaz, R. and Behr, J.G. (2010). Discrete-event simulation. *MODELING AND SIMULATION FUNDAMENTALS*, p. 57.

du Toit, G. (2007 April). Promoting conservation agriculture in south africa: a case study among commercial grain producers in the north west province.
Available at: http://www.bfap.co.za/documents/research%20reports/Conservation%20agriculture%20in%20South%20Africa%20-%20A%20case%20stydy%20(2007).pdf

Eyraud, L., Wane, A.A., Zhang, C. and Clements, B.J. (2011). Who's going green and why? trends and determinants of green investment. *IMF Working Papers*, pp. 1–38.

Farmer, J.D. and Foley, D. (2009). The economy needs agent-based modelling. *Nature*, vol. 460, no. 7256, pp. 685–686.

Fin24 (2014 June). Land reform proposals spell disaster. Accessed on: 07 July 2014. Available at: http://www.fin24.com/Economy/Land-reform-proposals-spell-disaster-20140627

Forrester, J.W. and Senge, P.M. (1980). Tests for building confidence in system dynamics models. *System dynamics, TIMS studies in management sciences*, vol. 14, pp. 209–228.

Geels, F.W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, vol. 1, no. 1, pp. 24–40.

Gen, M., Cheng, R. and Lin, L. (2008). *Network models and optimization: Multiobjective genetic algorithm approach*. Springer Science & Business Media.

Goldenberg, A., Zheng, A.X., Fienberg, S.E. and Airoldi, E.M. (2010). A survey of statistical network models. *Foundations and Trends® in Machine Learning*, vol. 2, no. 2, pp. 129–233.

Hall, R. (2009 July). Land reform in south africa: Constructive aims and positive outcomes - reflecting on experiences on the way to 2014. Seminar Report 20, Konrad-Adenauer-Stiftung. Accessed on: 07 July 2014.
Available at: http://www.kas.de/wf/doc/kas_18654-544-1-30.pdf

Haraldsson, H.V. (2000). Introduction to system and causal loop diagrams. *System Dynamic Course, Lumes, Lund University, Sweden*.

Hilchey, D.L., Gillespie Jr., G.W., Kay, D.L. and Smith, R.D. (2008). The impact of agriculture: It's more than economic (part 1). Tech. Rep.. Accessed on: 07 July 2014.
Available at: http://cardi.cornell.edu/cals/devsoc/outreach/cardi/publications/loader.cfm?csModule=security/getfile&PageID=233315

Holland, J.H. (1992). Complex adaptive systems. *Daedalus*, pp. 17–30.

Hough, E.C. and Nell, W.T. (2002). The financial aspect of growing organic wine grapes in the vredendal district. *M. Agric thesis submitted in the Department of Agriculture. University of the Free State, Bloemfontein*.

IAASTD (2009). *Agriculture at a Crossroads: Synthesis Report*. International Assessment of Agricultural Knowledge, Science and Technology for Development.

Jackson, M.C. (2003). *Systems thinking: Creative holism for managers*. Wiley Chichester.

Jacob, M. (2013). Discrete event simulation. *Resonance*, vol. 18, no. 1, pp. 78–86.

Janssen, M.A. (2005). Agent-based modelling. *Modelling in ecological economics*, pp. 155–172.

Kemp, R. and van Lente, H. (2011). The dual challenge of sustainability transitions. *Environmental Innovation and Societal Transitions*, vol. 1, no. 1, pp. 121–124.

Kim, D.H. (1992). Guidelines for drawing causal loop diagrams. *The Systems Thinker*, vol. 3, no. 1, pp. 5–6.

Lankoski, J., Ollikainen, M. and Uusitalo, P. (2006). No-till technology: benefits to farmers and the environment? theoretical analysis and application to finnish agriculture. *European Review of Agricultural Economics*, vol. 33, no. 2, pp. 193–221.

Maani, K.E. and Cavana, R.Y. (2012). *Systems Thinking, System Dynamics*. Second edition edn. PEARSON.

Macal, C.M. and North, M.J. (2010). Tutorial on agent-based modelling and simulation. *Journal of simulation*, vol. 4, no. 3, pp. 151–162.

Macal, C.M., North, M.J. and Pieper, G. (2007). Agent-based modeling and simulation for exascale computing. Accessed on: 04 May 2015.
Available at: http://scidacreview.org/0802/html/abms.html

Maidstone, R. (2012). Discrete event simulation, system dynamics and agent based simulation: Discussion and comparison. *System*, pp. 1–6.

Midgley, G. (2006). Systems thinking for evaluation. *Systems Concepts in Evaluation: An Expert Anthology. Point Reyes, CA: EdgePress*, pp. 11–34.

Musango, J.K., Brent, A.C. and Bassi, A.M. (2014). Modelling the transition towards a green economy in south africa. *Technological Forecasting and Social Change*, vol. 87, pp. 257–273.

Musango, J.K., Brent, A.C., van Niekerk, J.B.S., Jonker, W.D., Pienaar, A.P., York, T.A., Oosthuizen, J., Duminy, L. and de Kock, I.H. (2015). A system dynamics approach to understand the implications of a green economy transition in the western cape province of south africa. *33rd International Conference of the System Dynamics Society*.

National Planning Commission (2013). Our future - make it work. Chapter 5. Accessed on: 29 March 2014.
Available at: http://www.npconline.co.za/pebble.asp?relid=25

Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E. *et al.* (2014). Climate change effects on agriculture: Economic responses to biophysical shocks. *Proceedings of the National Academy of Sciences*, vol. 111, no. 9, pp. 3274–3279.

Newman, M.E., Watts, D.J. and Strogatz, S.H. (2002). Random graph models of social networks. *Proceedings of the National Academy of Sciences*, vol. 99, no. suppl 1, pp. 2566–2572.

Østreng, W. (2005). Reductionism versus holism–contrasting approaches. *Consilience. Interdisciplinary Communications*, vol. 2006, pp. 11–14.

Ouyang, M. (2014). Review on modeling and simulation of interdependent critical infrastructure systems. *Reliability engineering & System safety*, vol. 121, pp. 43–60.

Pejić-Bach, M. and Čerić, V. (2007). Developing system dynamics models with" step-by-step" approach. *Journal of information and organizational sciences*, vol. 31, no. 1, pp. 171–185.

Rihani, S. (2002). *Complex Systems Theory and Development Practice: understanding non-linear realities.* Zed Books.

Rotmans, J. and Loorbach, D. (2009). Complexity and transition management. *Journal of Industrial Ecology*, vol. 13, no. 2, pp. 184–196.

SAinfo (2012 November). The nine provinces of south africa.
Available at: http://www.southafrica.info/about/geography/provinces.htm#.VdWDpvmqpBc

SAPA (2014 June). Da: New land reform proposals are a recipe for disaster. Accessed on: 08 July 2014.
Available at: http://mg.co.za/article/2014-06-24-da-new-land-reform-proposals-are-recipe-for-disaster

Sargent, R.G. (2013). Verification and validation of simulation models. *Journal of Simulation*, vol. 7, no. 1, pp. 12–24.

Sonnessa, M. (2004). *Modelling and simulatio of complex systems.* Master's thesis, Unversita di Torino.

Stave, K.A. (2003). A system dynamics model to facilitate public understanding of water management options in las vegas, nevada. *Journal of Environmental Management*, vol. 67, no. 4, pp. 303–313.

Sterman, J.D. (2000). *Business dynamics: systems thinking and modeling for a complex world*, vol. 19. Irwin/McGraw-Hill Boston.

Strogatz, S.H. (2001). Exploring complex networks. *Nature*, vol. 410, no. 6825, pp. 268–276.

Sweeney, L.B. and Sterman, J.D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review*, vol. 16, no. 4, pp. 249–286.

Tedeschi, L., Nicholson, C. and Rich, E. (2011). Using system dynamics modelling approach to develop management tools for animal production with emphasis on small ruminants. *Small Ruminant Research*, vol. 98, no. 1, pp. 102–110.

Tuomisto, H., Hodge, I., Riordan, P. and Macdonald, D. (2012). Does organic farming reduce environmental impacts? a meta-analysis of european research. *Journal of Environmental Management*, vol. 112, no. 0, pp. 309 – 320. ISSN 0301-4797.
Available at: http://www.sciencedirect.com/science/article/pii/S0301479712004264

UNECE (2008). What does green economy mean? Accessed on: 1 April 2014.
Available at: http://www.unece.org/greeneconomywelcome/what-does-green-economy-mean.html

UNEP (2003). What is the "green economy"? Accessed on: 1 April 2014.
Available at: http://www.unep.org/greeneconomy/AboutGEI/WhatisGEI/tabid/29784/Default.aspx

UNEP (2013*a*). Green economy and trade - trends, challenges and opportunities. Tech. Rep.. Accessed on: 12 July 2014.
Available at: http://unep.org/greeneconomy/GreenEconomyandTrade/GreenEconomyandTradeReport/tabid/106194/language/en-US/Default.aspx

UNEP (2013*b*). Green economy scoping study: South african green economy modelling report (SAGEM) - focus on natural resources management, agriculture, transport and energy sectors. Accessed on: 1 April 2014.
Available at: http://www.unep.org/greeneconomy

UNEP (2013*c*). The transition to a green economy: Benefits, challenges and risks from a sustainable development perspective. Accessed on: 29 March 2014.
Available at: http://www.uncsd2012.org/index.php?page=view&type=400&nr=12&menu=45

van Niekerk, J.B.S., Brent, A.C. and Musango, J.K. (2015). Agriculture sector implications of a green economy transition in the western cape province of south africa. *International Association for Management of Technology* , vol. 24, pp. 591–610.
Available at: http://www.iamot2015.com/2015proceedings/documents/P078.pdf

Venter, D. (2015). Why you should consider no-till on your farm! Accessed on: 22 June 2015.
Available at: http://notillclub.com/files/no-till-on-your-farm.pdf

Verbong, G.P. and Geels, F.W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change*, vol. 77, no. 8, pp. 1214–1221.

Vink, N. and Tregurtha, N. (2005). Performance and future prospects: An overview. *Agriculture and mariculture*, pp. 1–36.

Vlachos, D., Georgiadis, P. and Iakovou, E. (2007). A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains. *Computers & Operations Research*, vol. 34, no. 2, pp. 367–394.

Wainwright, J. and Mulligan, M. (2013). *Environmental modelling: finding simplicity in complexity*. John Wiley & Sons.

Western Cape Department of Agriculture (2005). Agricultural statistics in brief. Available at: http://www.elsenburg.com/economics/statistics/start.htm

Western Cape Government (2013*a*). Green is smart: Western cape green economy strategy framework 2013. Accessed on: 29 March 2014. Available at: http://wesgro.co.za/publications/publication/western-cape-government-green-economy-strategy-framework

Western Cape Government (2013*b*). National development plan 2030: Transition to a low carbon economy. Chapter 5. Accessed on: 29 March 2014. Available at: http://www.westerncape.gov.za/110green/documents

Wolfram, S. (1985 January). *Complex Systems Theory**. Master's thesis, The Institute for Advanced Study, Princeton NJ 08540.

Wooldridge, M. (2009). *An introduction to multiagent systems*. John Wiley & Sons.

Appendices

Appendix A

Stock and flow diagram modules

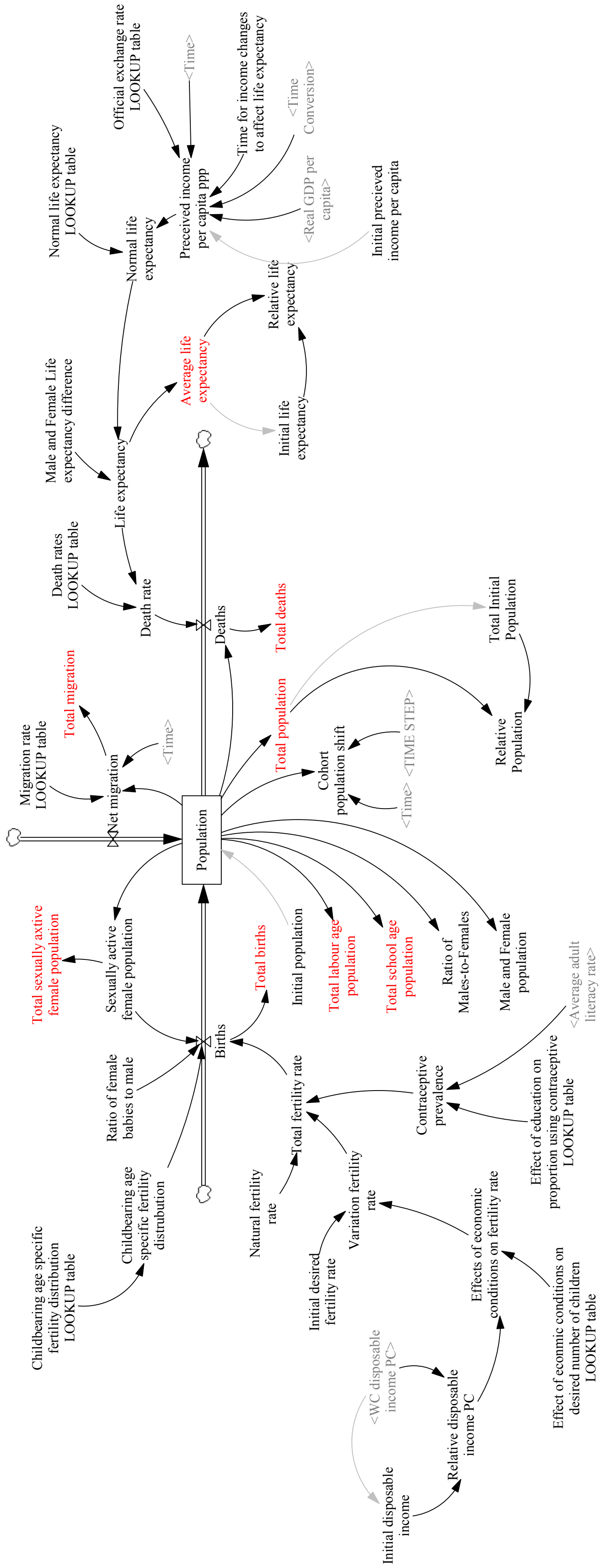

Figure A.1: The Western Cape population stock and flow module.

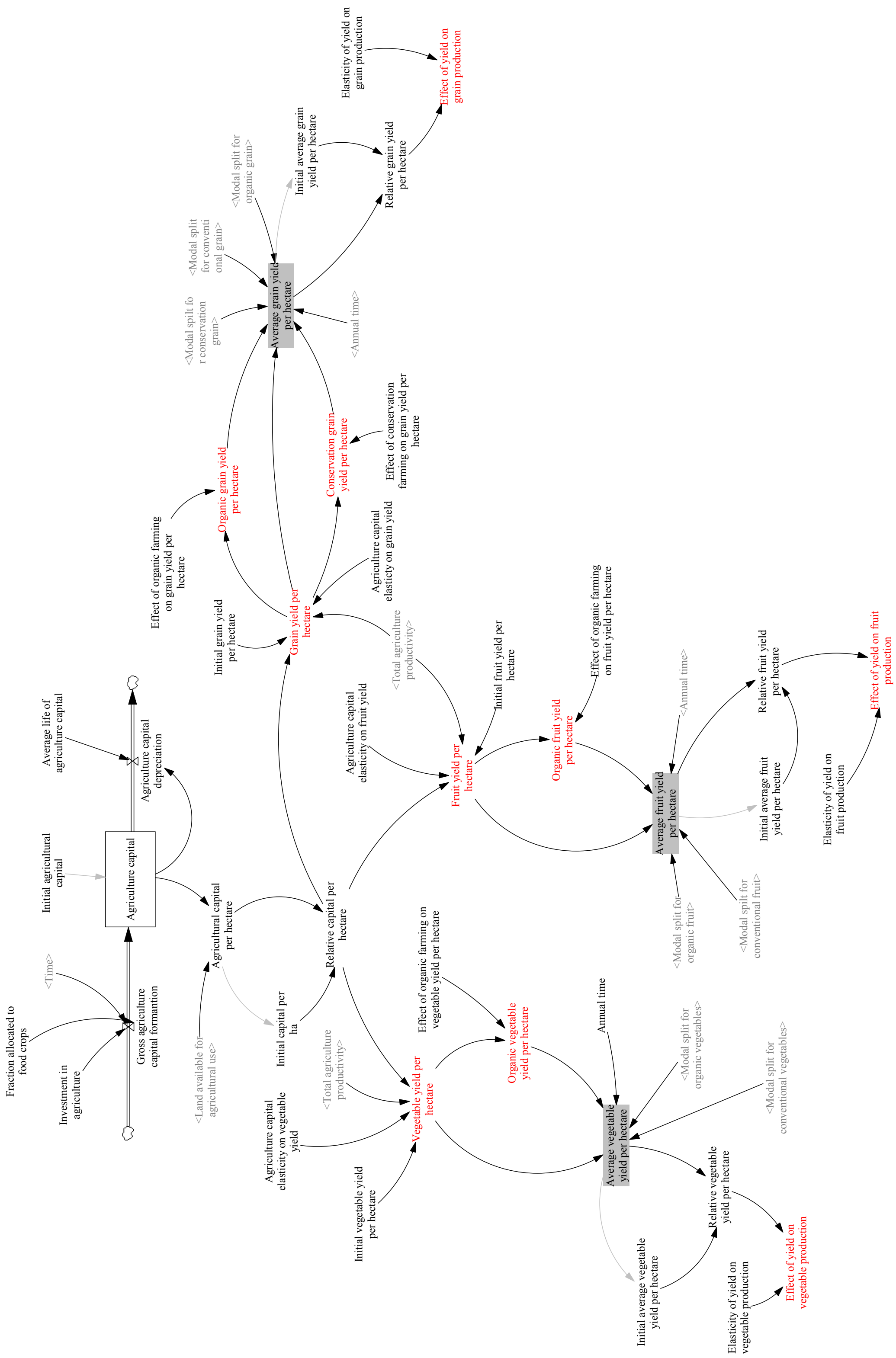

Figure A.2: Western Cape agriculture capital investment stock and flow module.

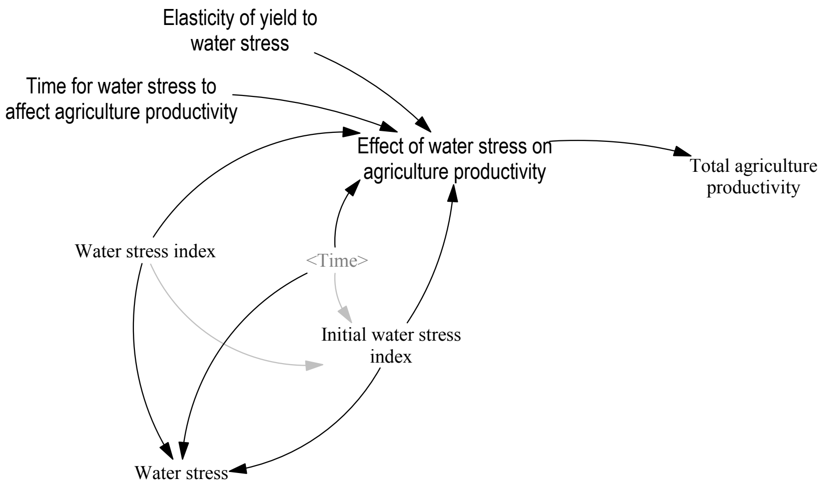

Figure A.3: Western Cape water stress stock and flow module.

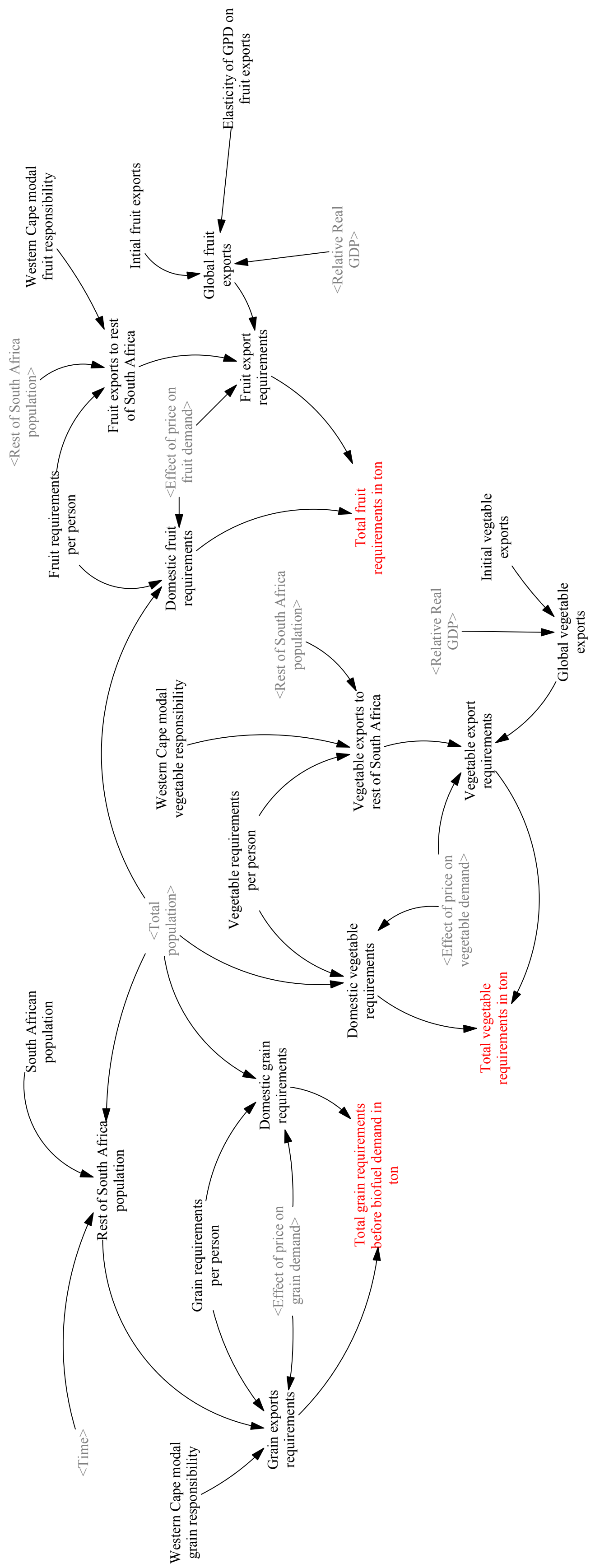

Figure A.4: Western Cape food demand stock and flow module.

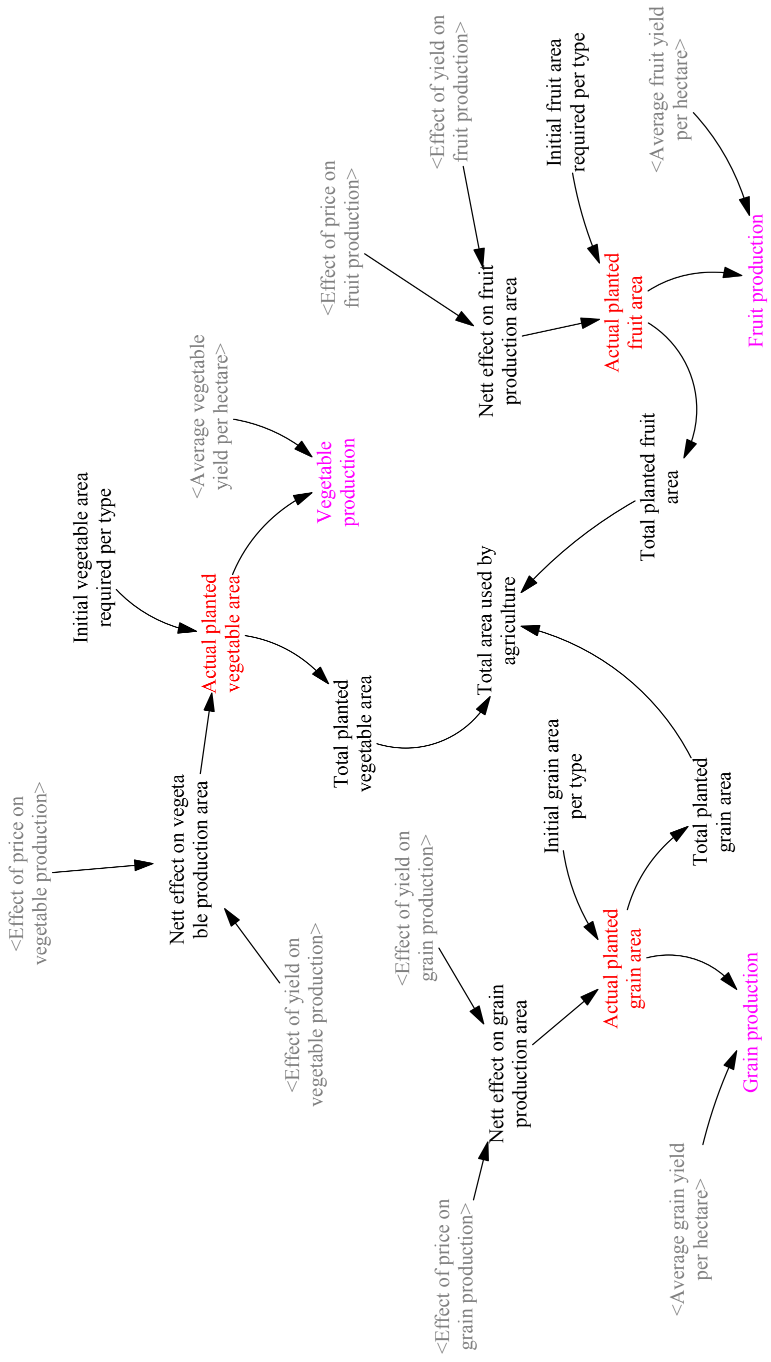

Figure A.5: Western Cape planted area stock and flow module.

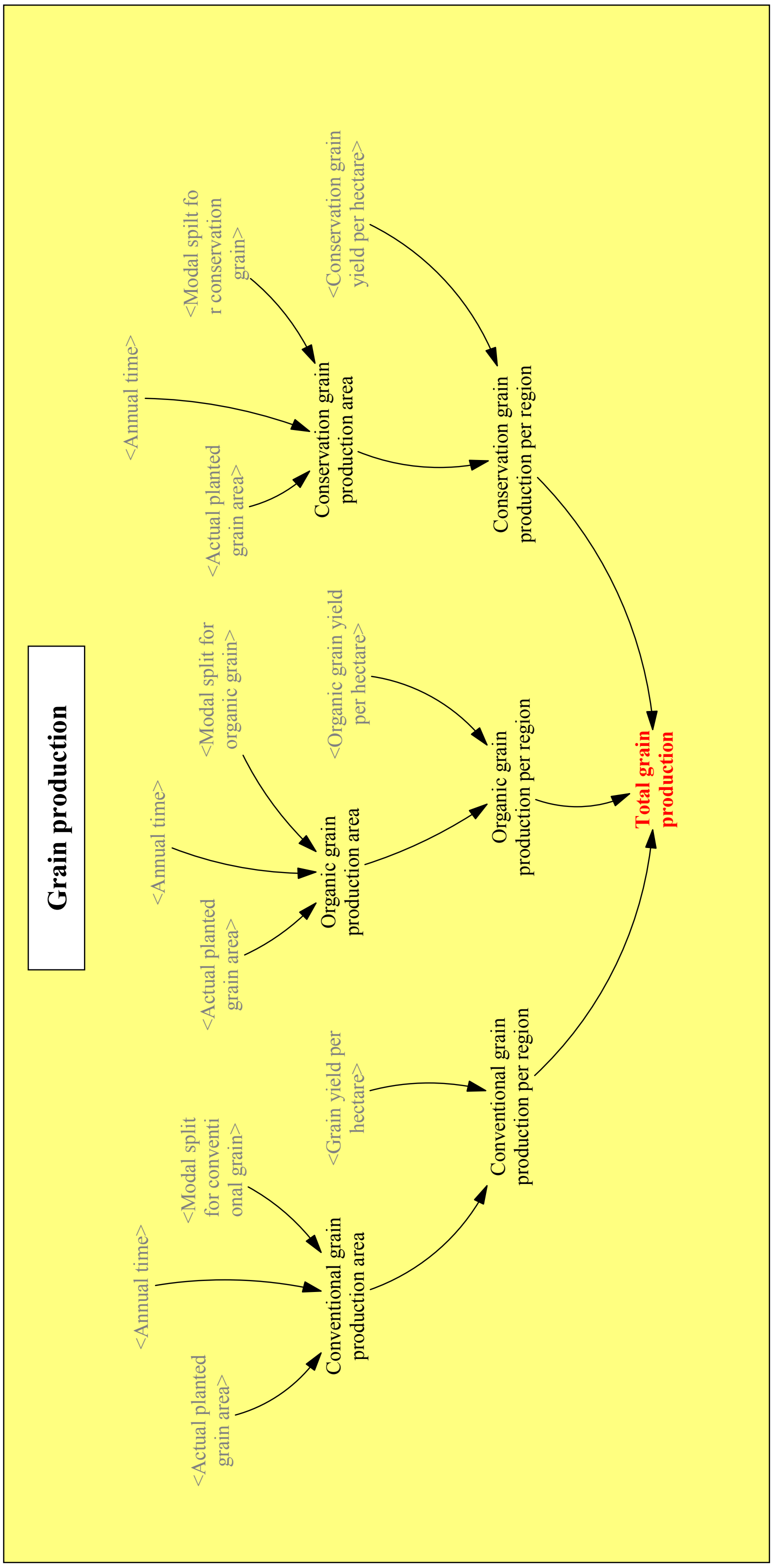

Figure A.6: Western Cape grain food crop production stock and flow module.

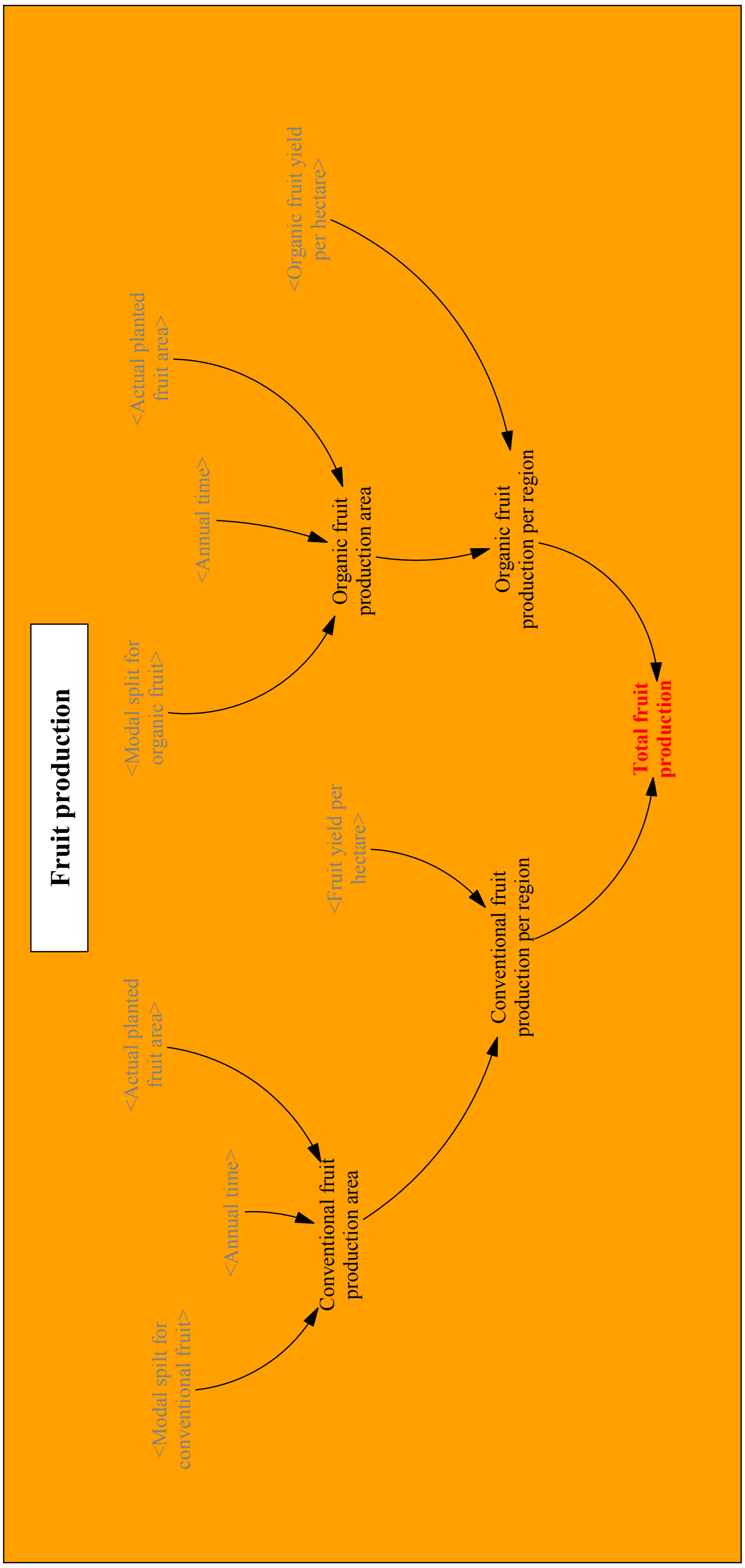

Figure A.7: Western Cape fruit food crop production stock and flow module.

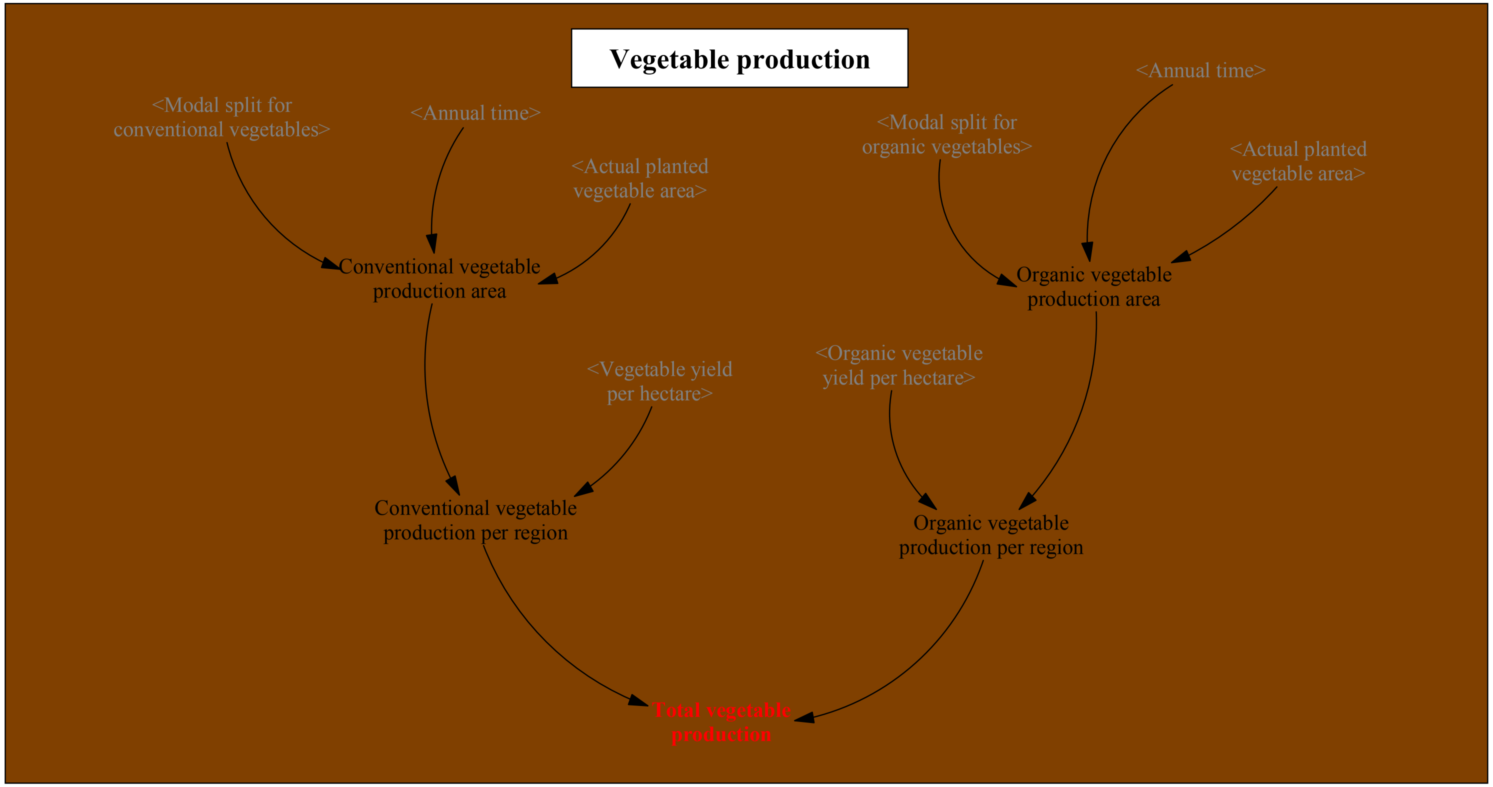

Figure A.8: Western Cape vegetable food crop production stock and flow module.

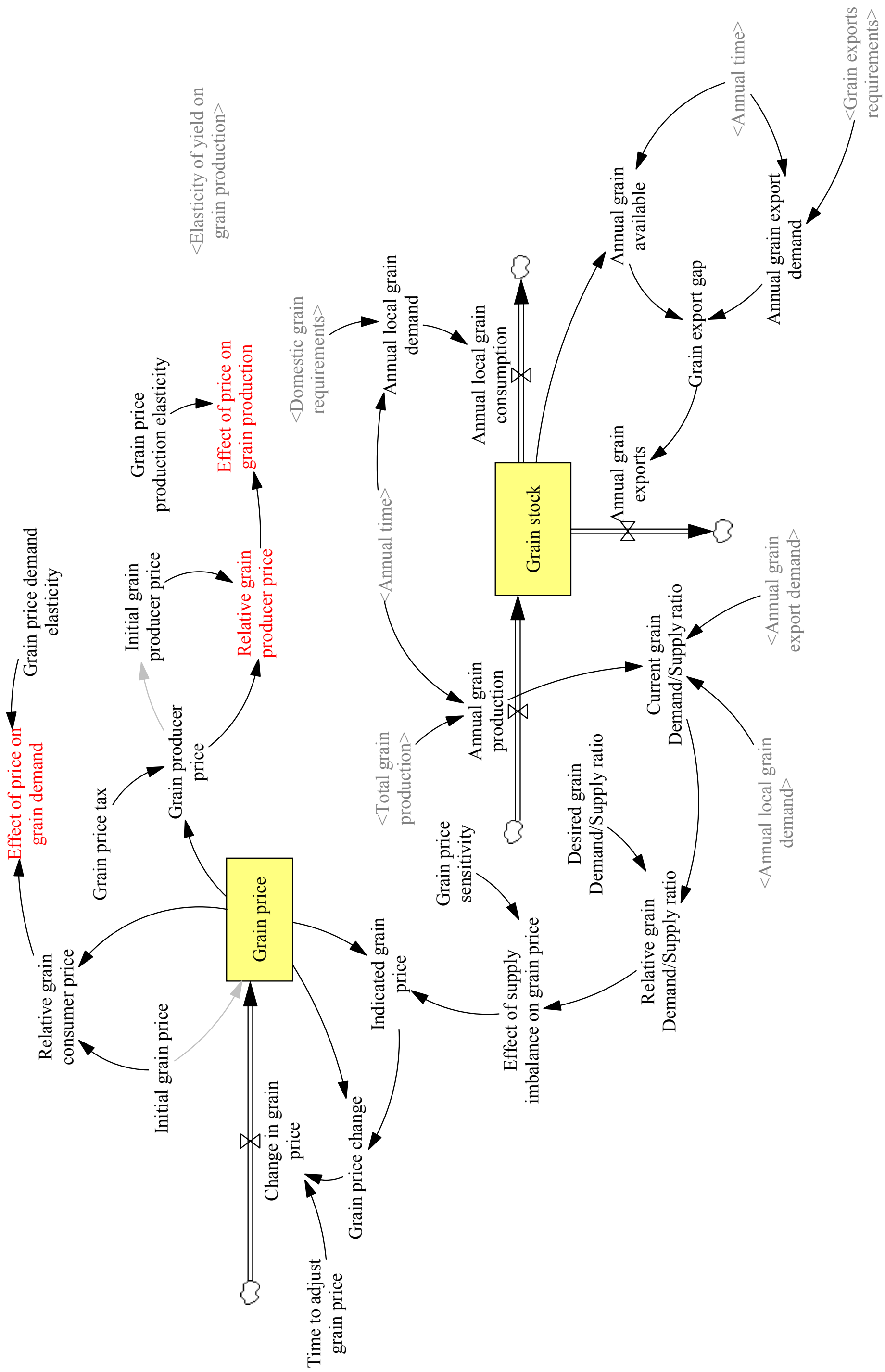

Figure A.9: Grain price stock and flow module for wheat, canola, and barley.

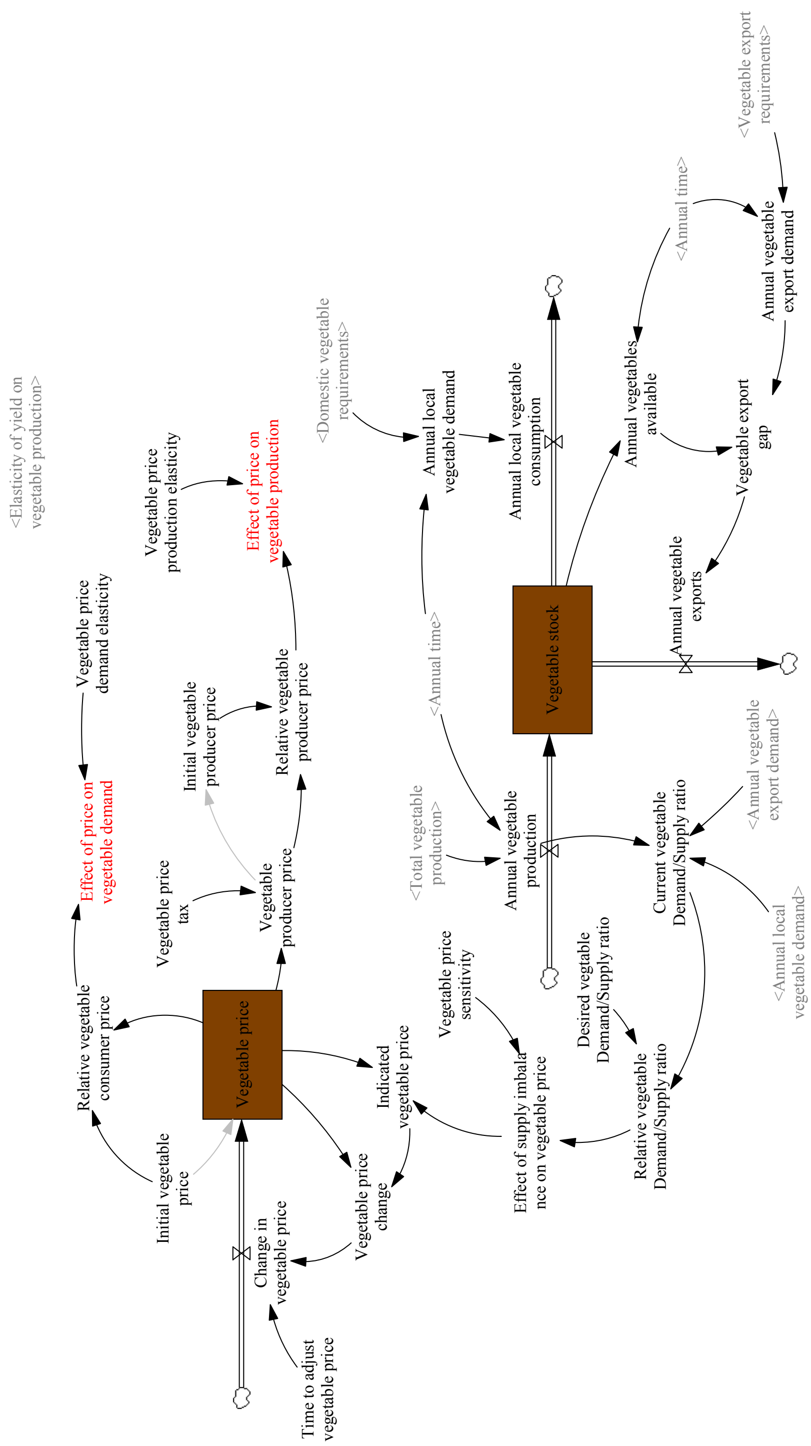

Figure A.10: Vegetable price stock and flow module for potatoes and onions.

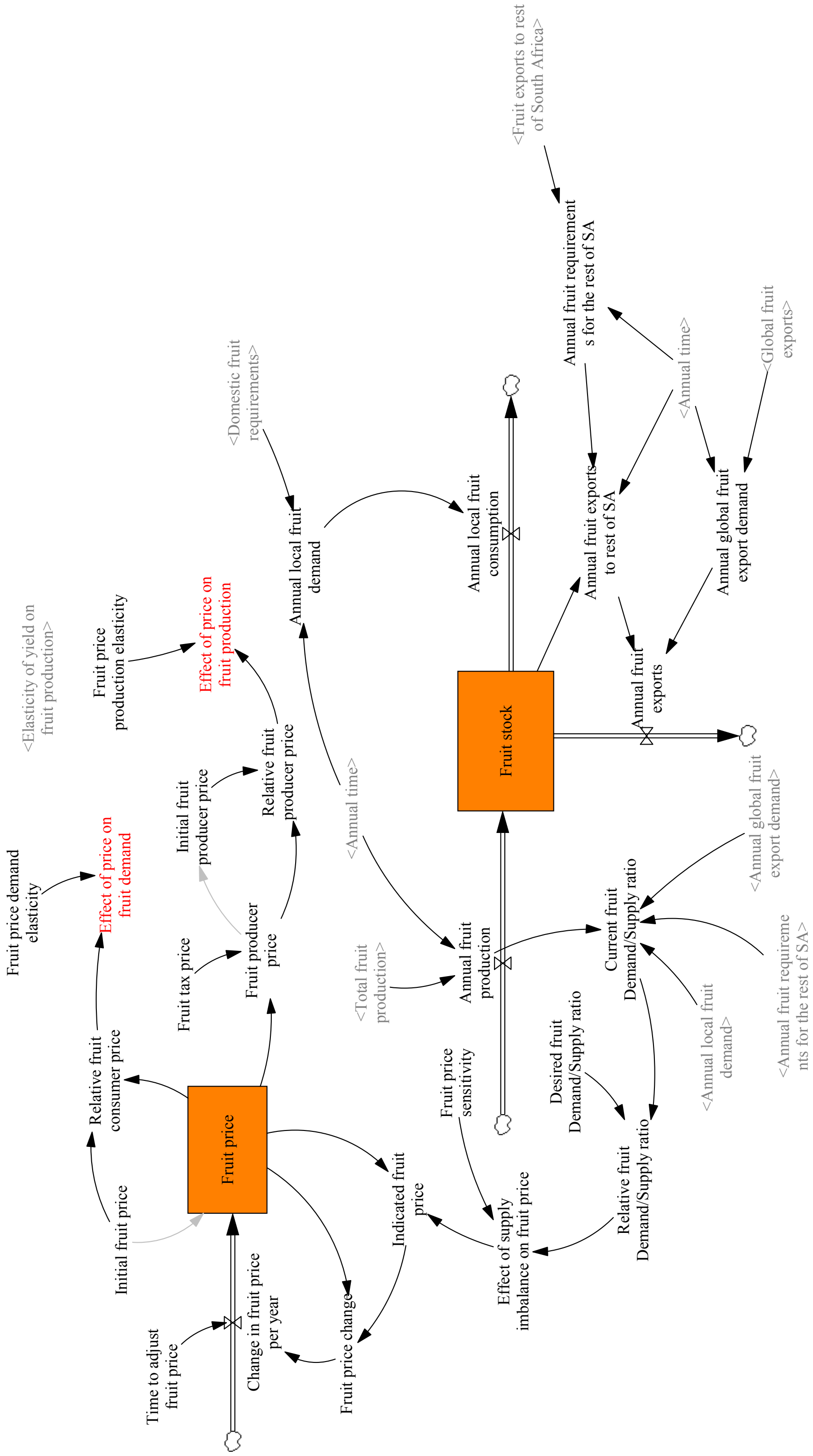

Figure A.11: Fruit price stock and flow module for apples, pears, citrus fruit, stone fruit, and wine and table grapes.

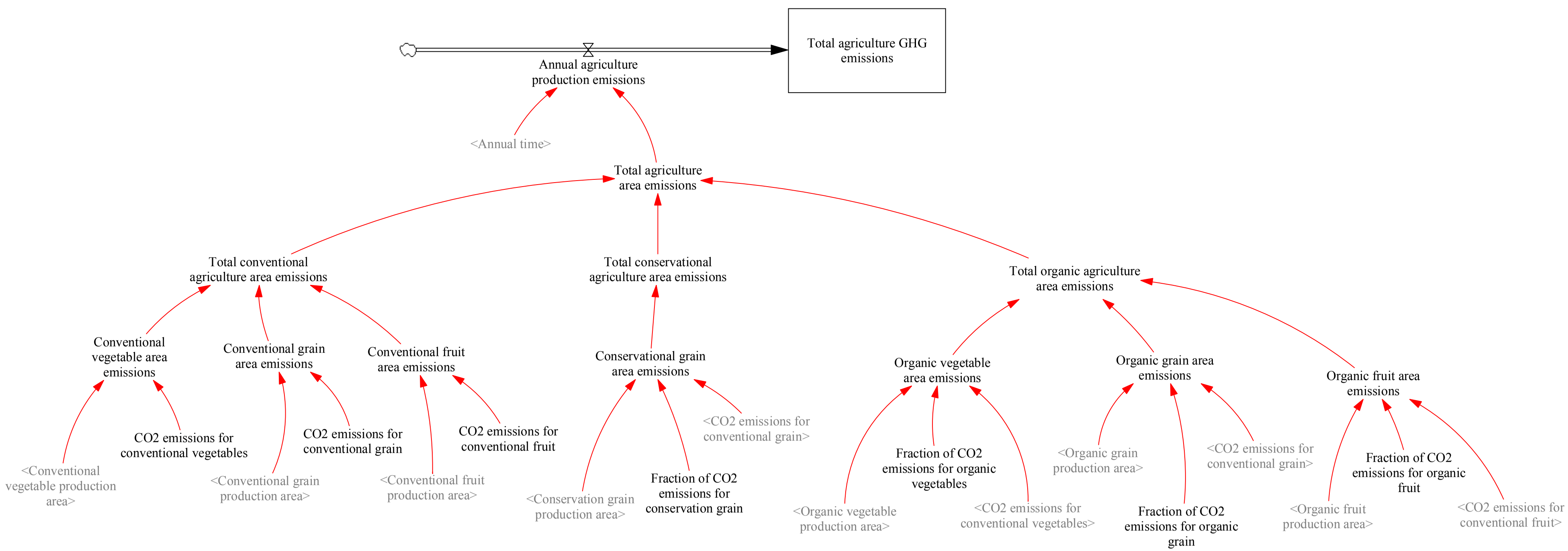

Figure A.12: The stock and flow module of food crop emissions, as a results of different production practices.

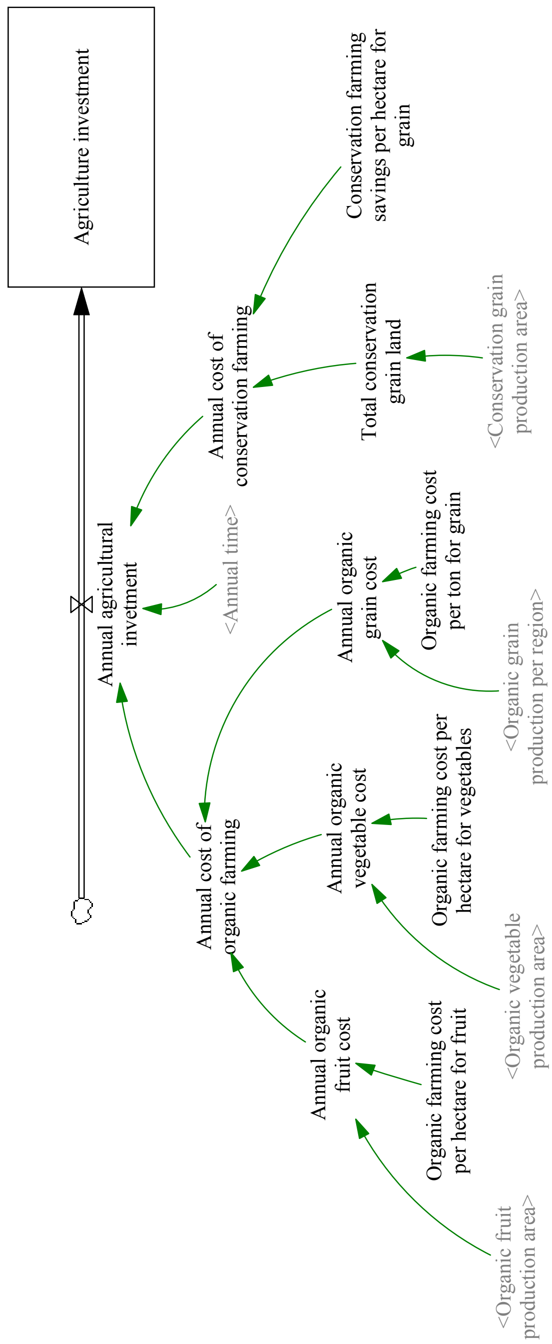

Figure A.13: The investment stock and flow module with different production practices.

Appendix B

Model validation

B.1 Sensitivity analysis test 1

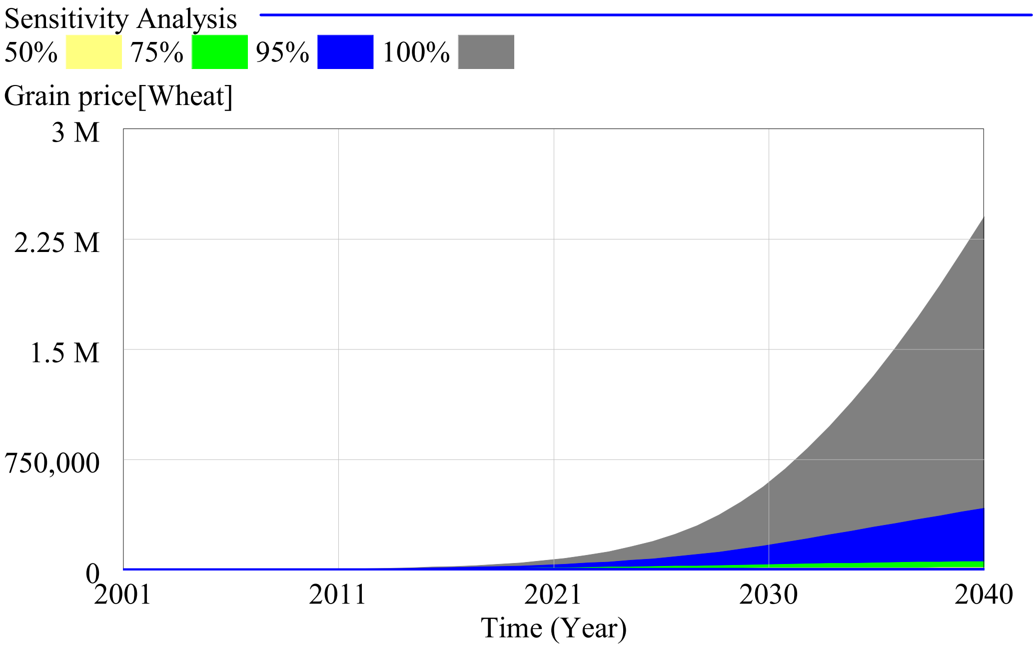

Figure B.1: The sensitivity analysis for wheat price when grain price demand elasticity is changed.

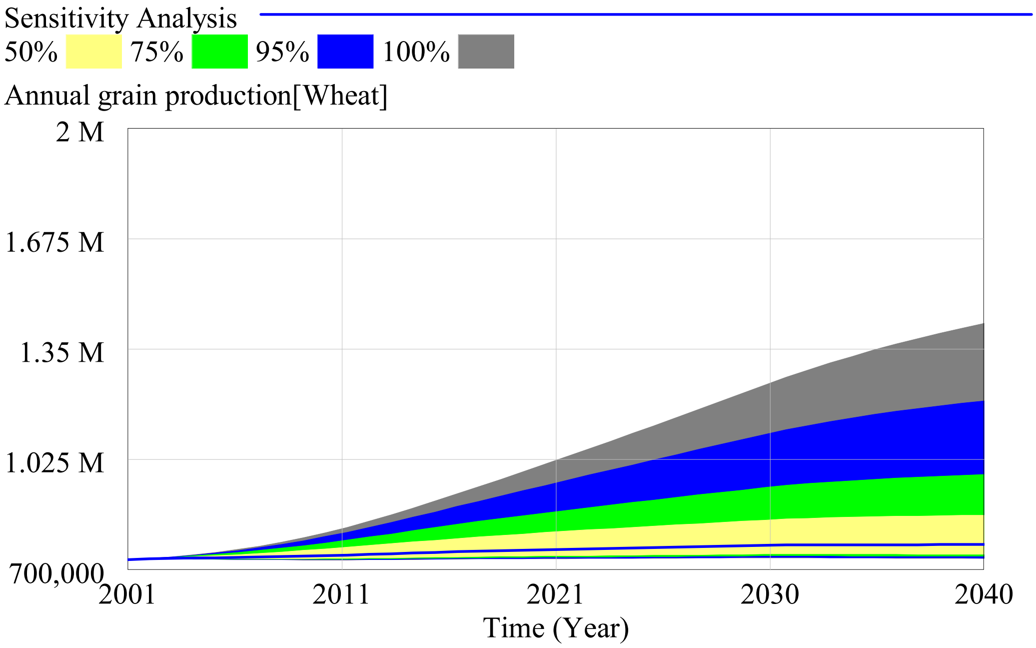

Figure B.2: The sensitivity analysis for wheat production when grain price demand elasticity is changed.

B.2 Sensitivity analysis test 2

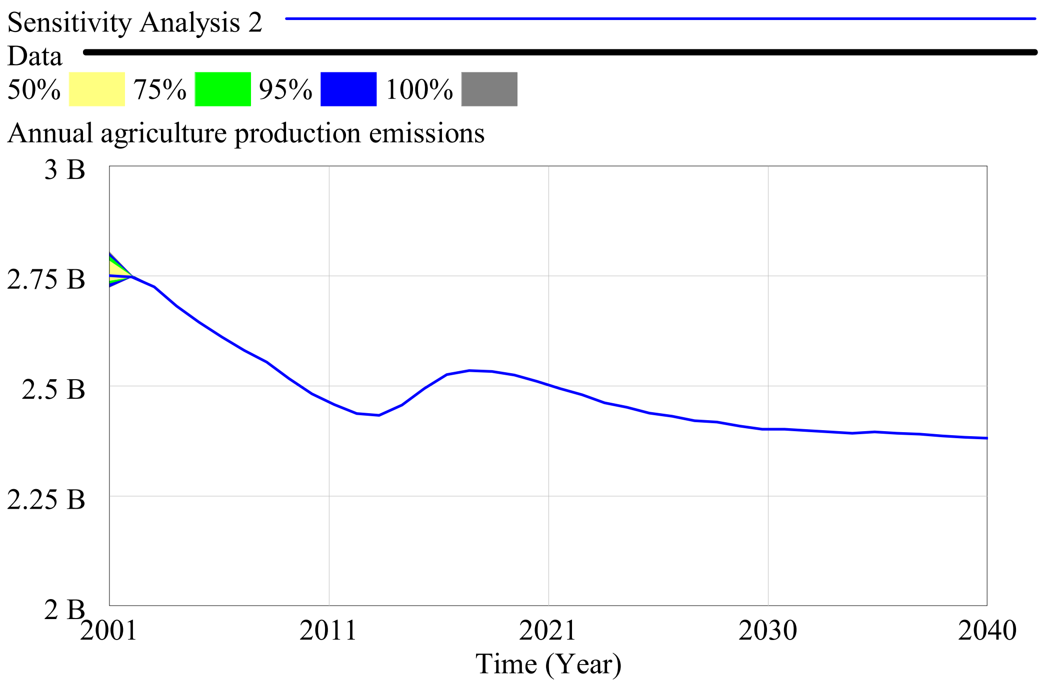

Figure B.3: The sensitivity analysis for apple production emissions when initial fruit area required per type is changed.

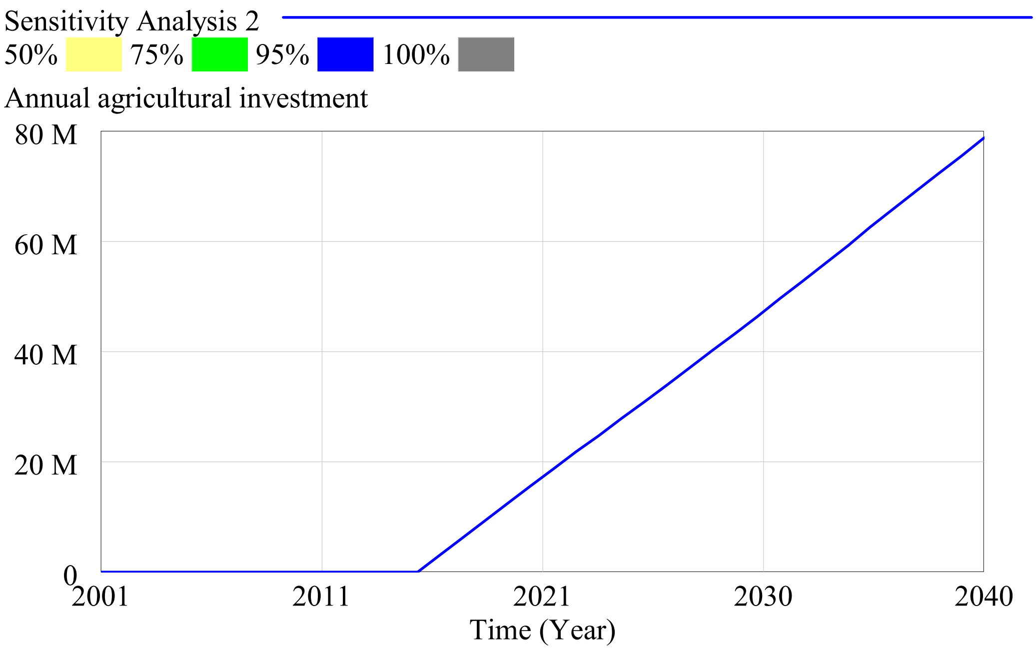

Figure B.4: The sensitivity analysis for apples' annual agricultural investment when initial fruit area required per type is changed.

Appendix C

Simulated results for yield for each of the 10 different food crop commodities

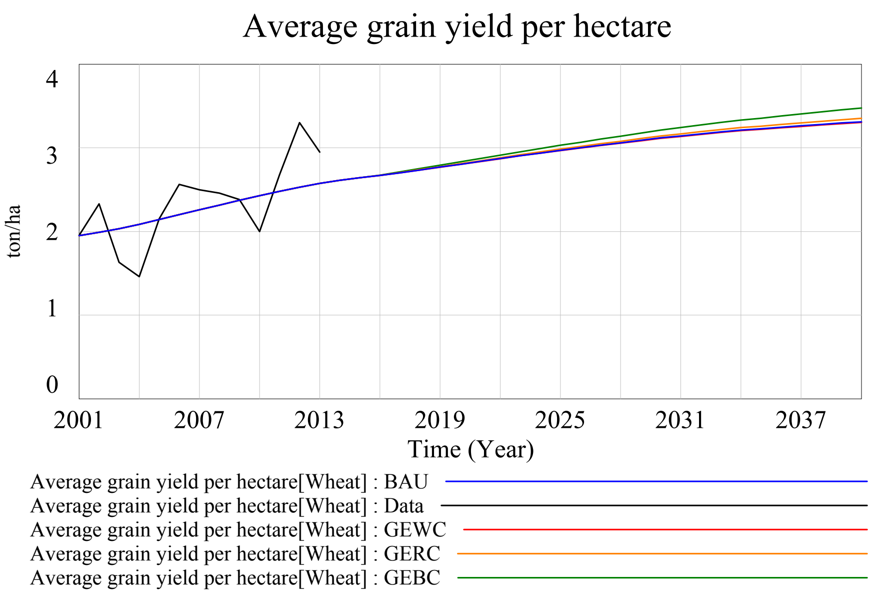

Figure C.1: Predicted wheat yield for the Western Cape.

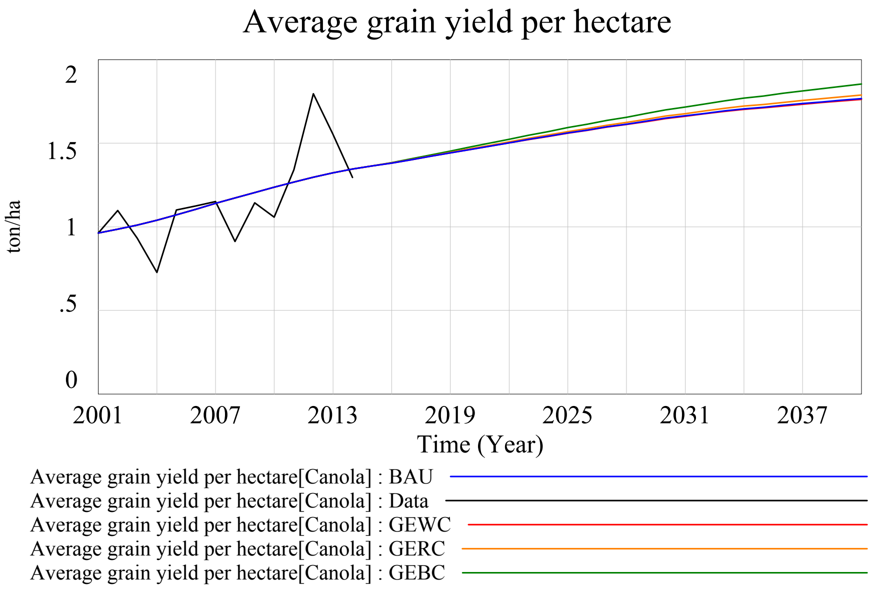

Figure C.2: Predicted canola yield for the Western Cape.

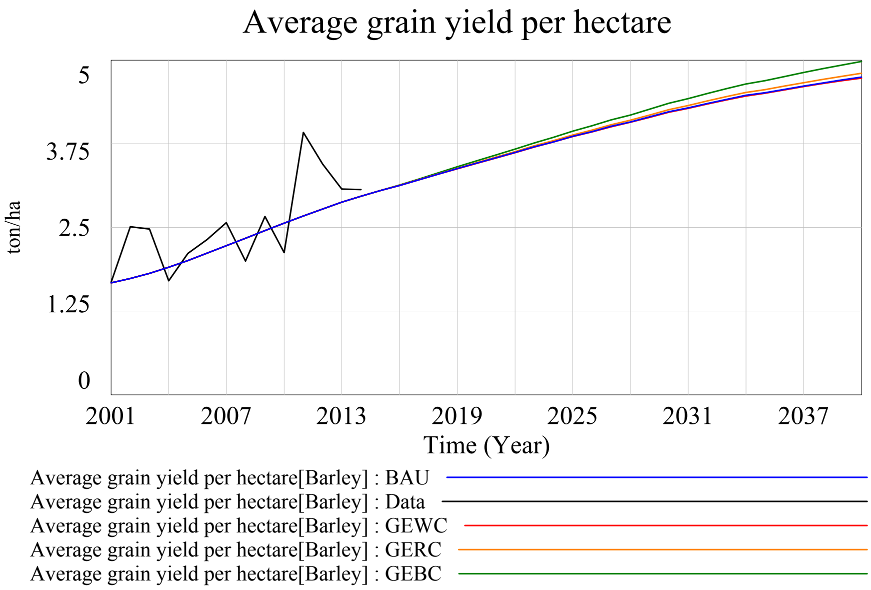

Figure C.3: Predicted barley yield for the Western Cape.

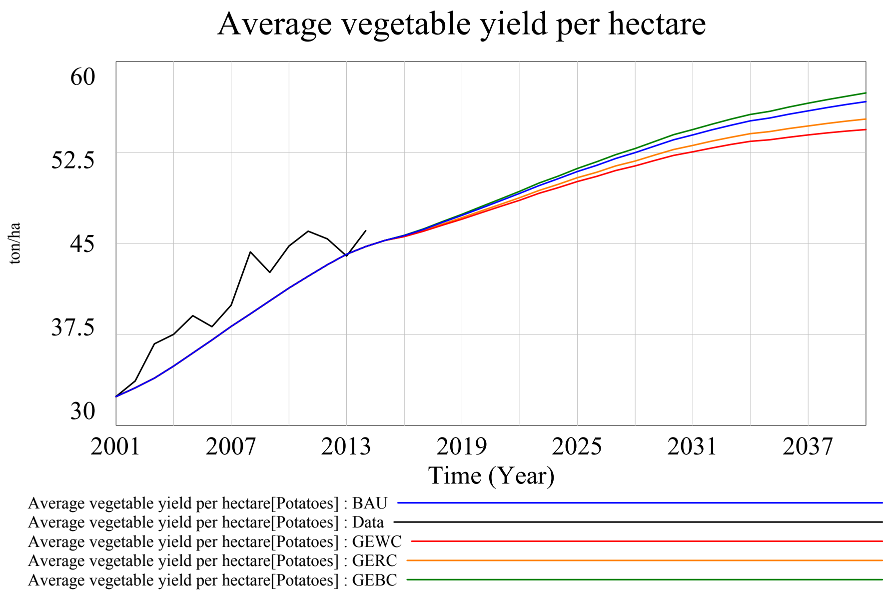

Figure C.4: Predicted potato yield for the Western Cape.

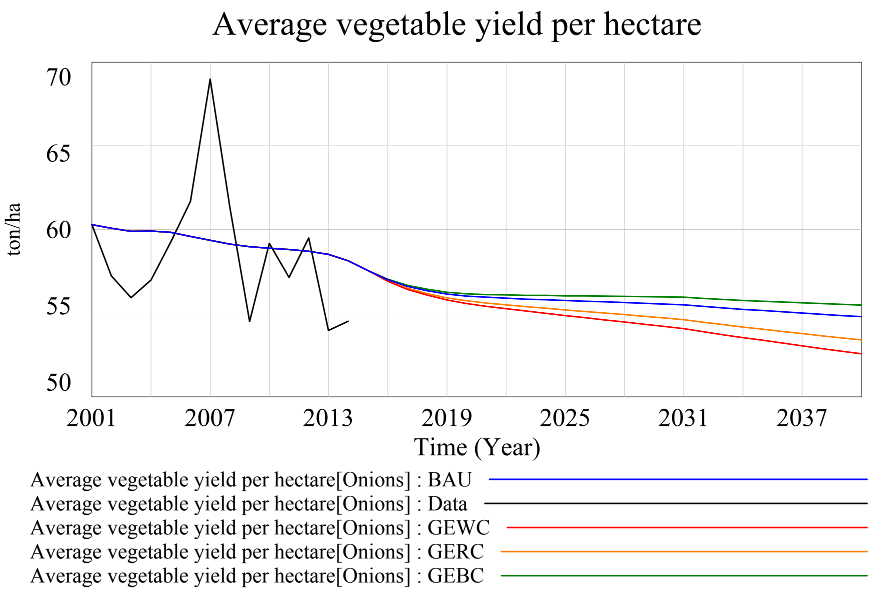

Figure C.5: Predicted onion yield for the Western Cape.

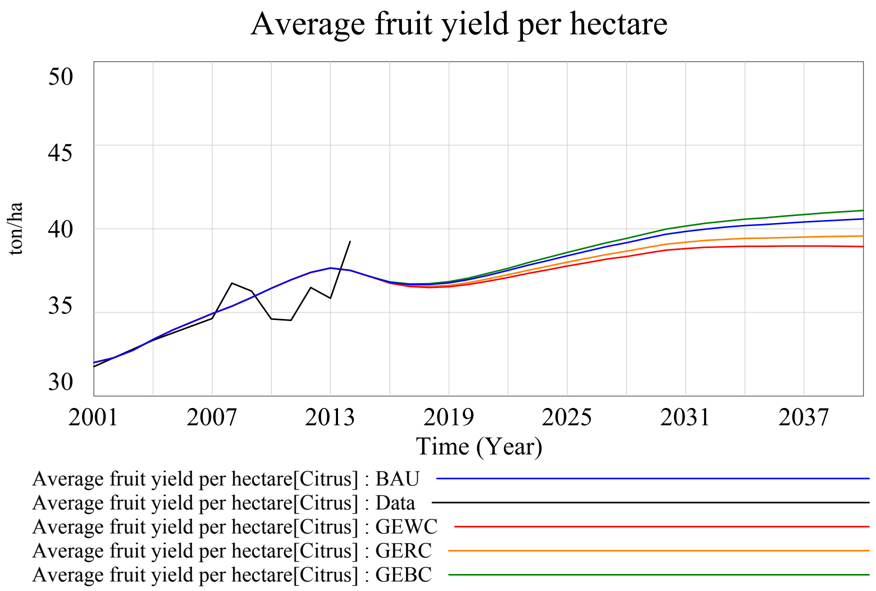

Figure C.6: Predicted citrus fruit yield for the Western Cape.

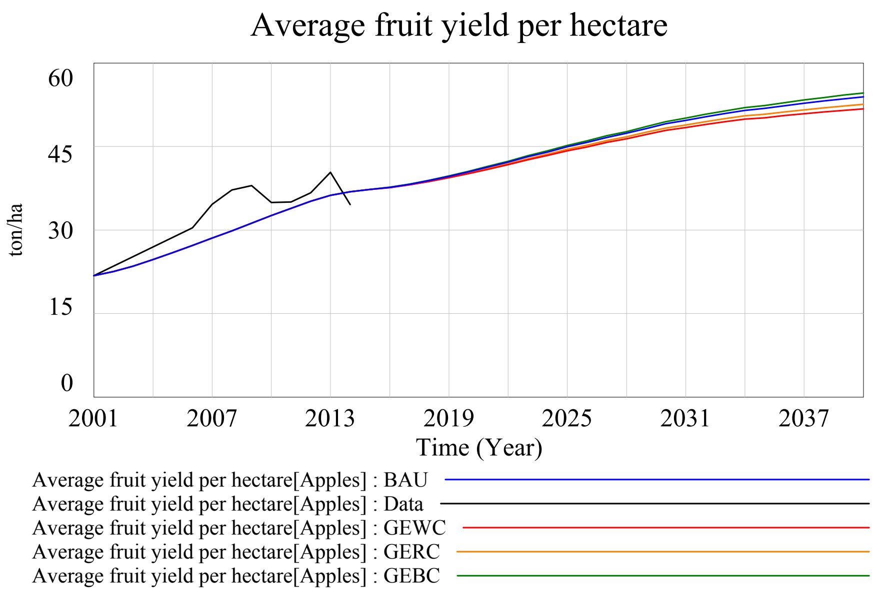

Figure C.7: Predicted apple yield for the Western Cape.

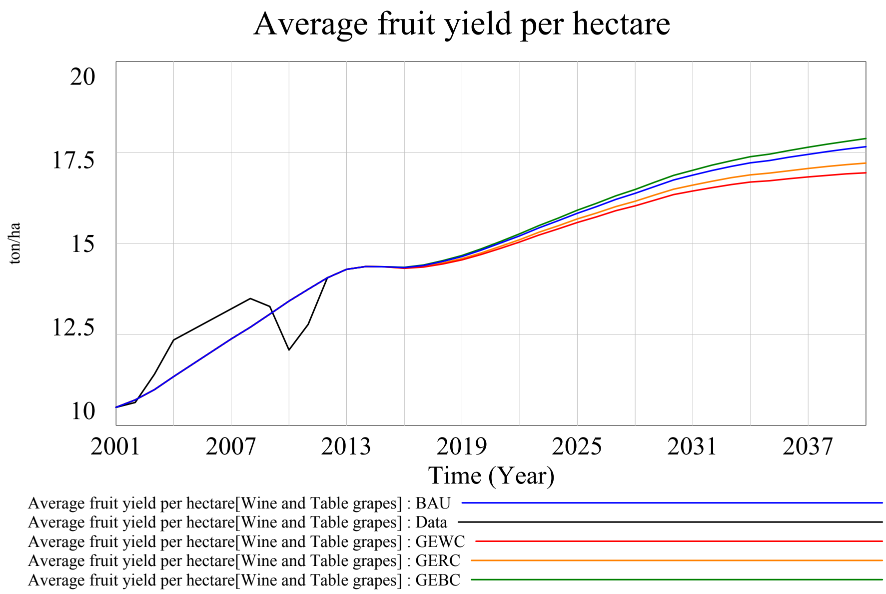

Figure C.8: Predicted wine and table grapes yield for the Western Cape.

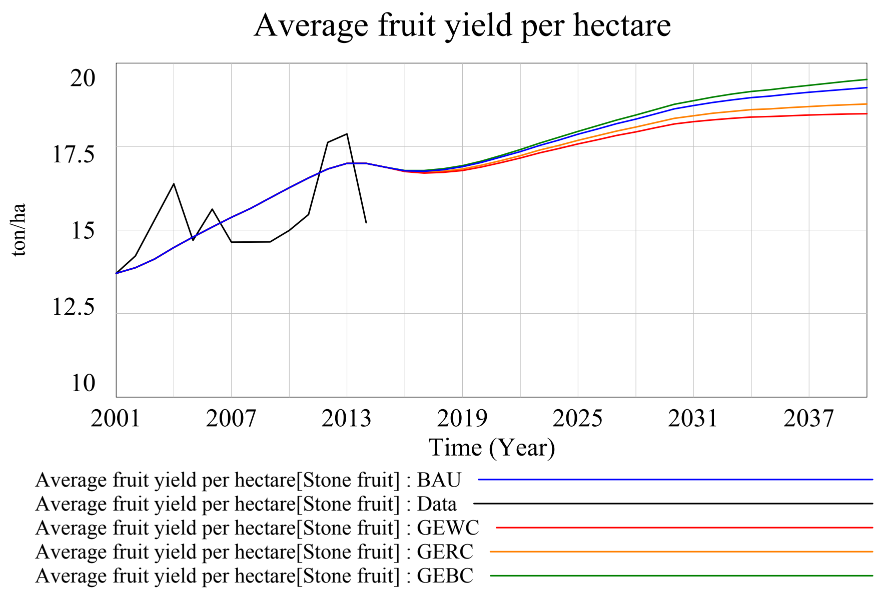

Figure C.9: Predicted stone fruit yield for the Western Cape.

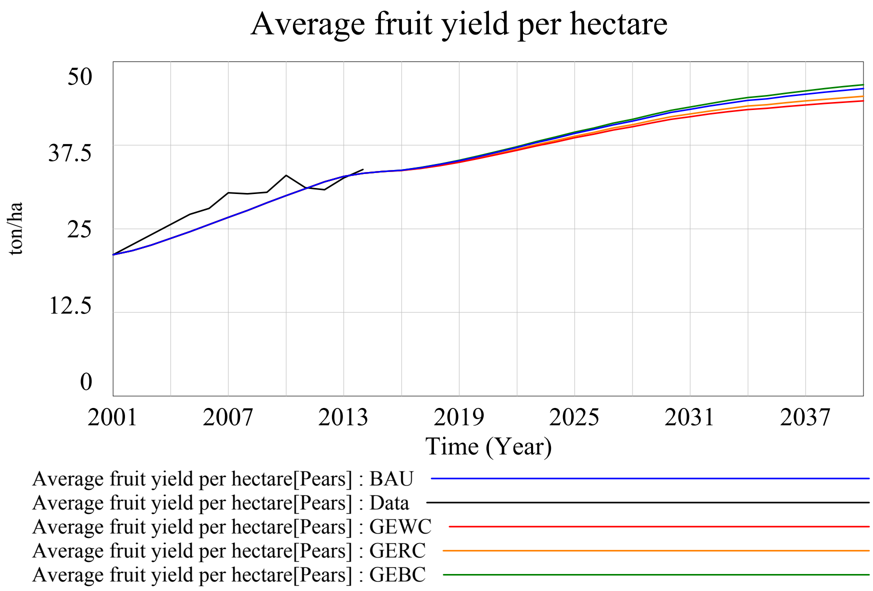

Figure C.10: Predicted pear yield for the Western Cape.

Appendix D

Simulated production results for each of the 10 different food crop commodities

The r-squared values ($\sqrt{R}$) for the production graphs is the BAU scenario compared to historical data according to Vensim's statistical tool.

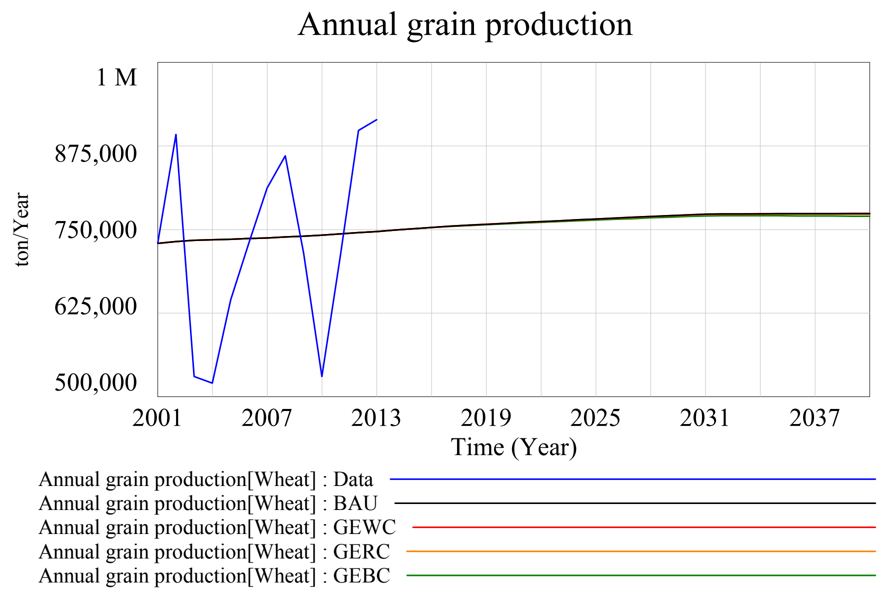

Figure D.1: Predicted wheat production for the Western Cape ($\sqrt{R} = 0.0182$).

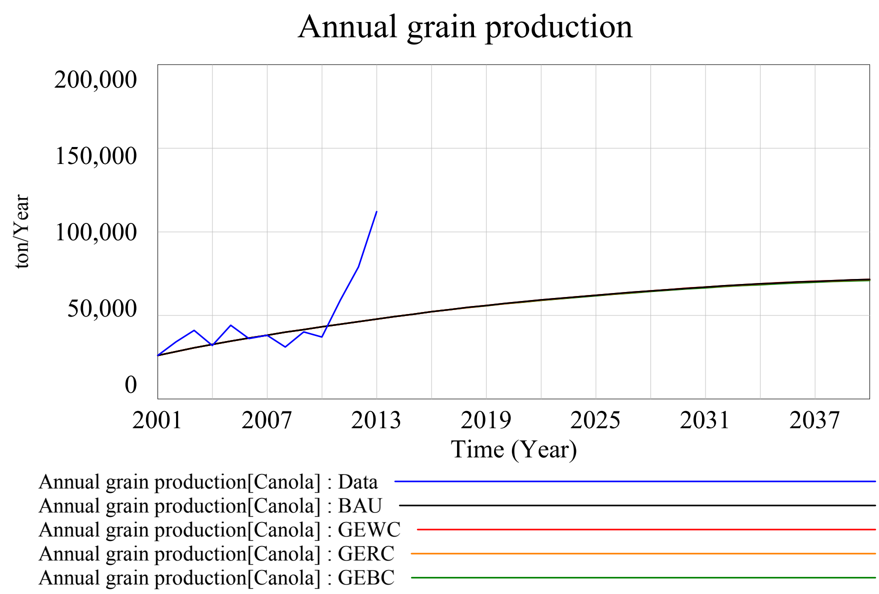

Figure D.2: Predicted canola production for the Western Cape ($\sqrt{R} = 0.162$).

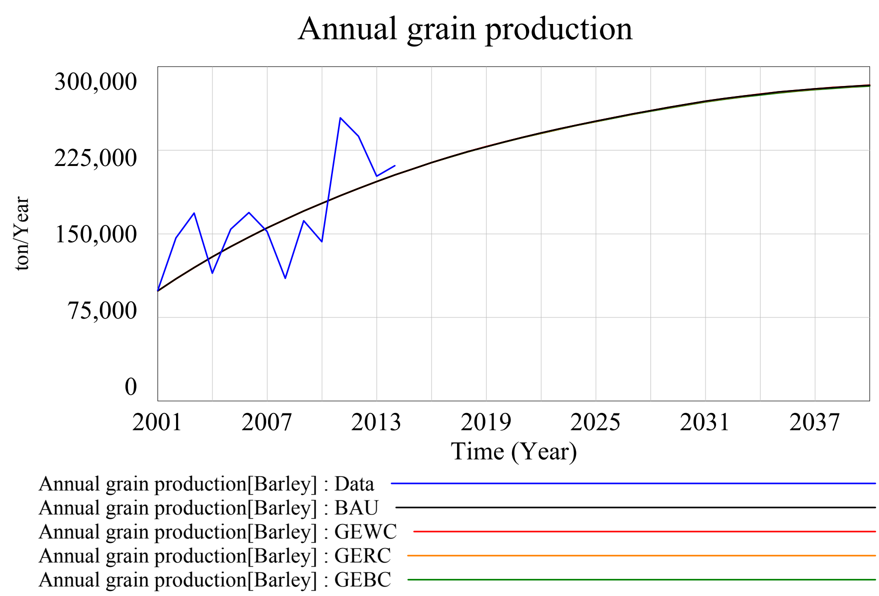

Figure D.3: Predicted barley production for the Western Cape ($\sqrt{R} = 0.424$).

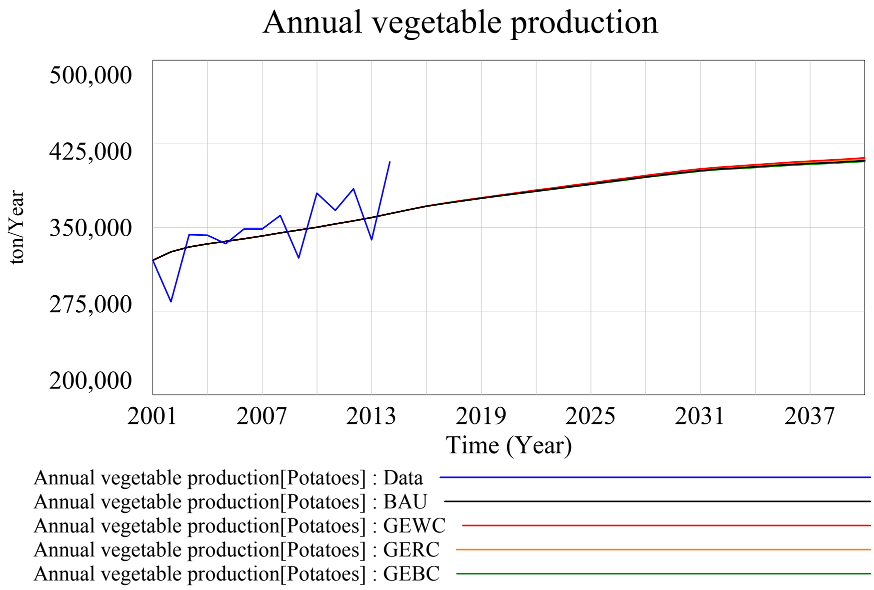

Figure D.4: Predicted potato production for the Western Cape ($\sqrt{R} = 0.385$).

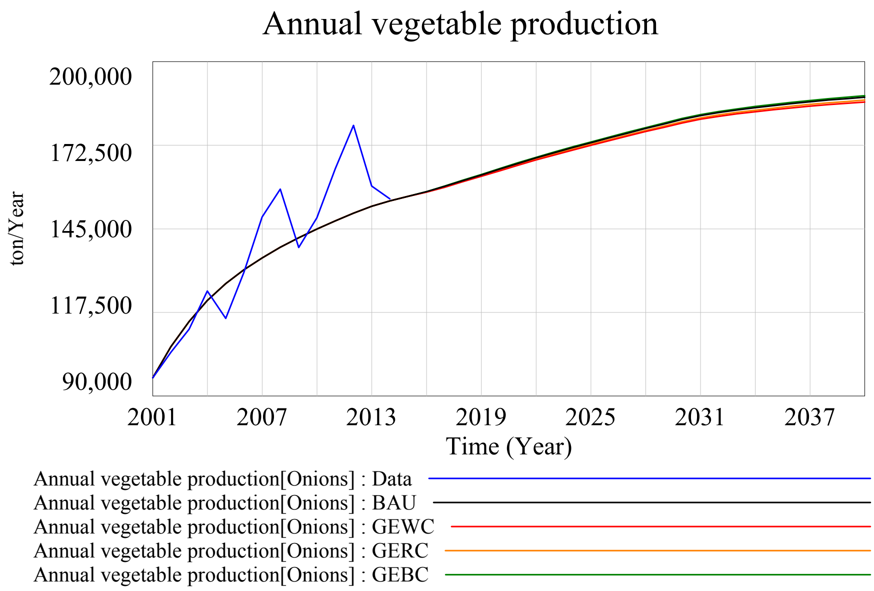

Figure D.5: Predicted onion production for the Western Cape ($\sqrt{R} = 0.765$).

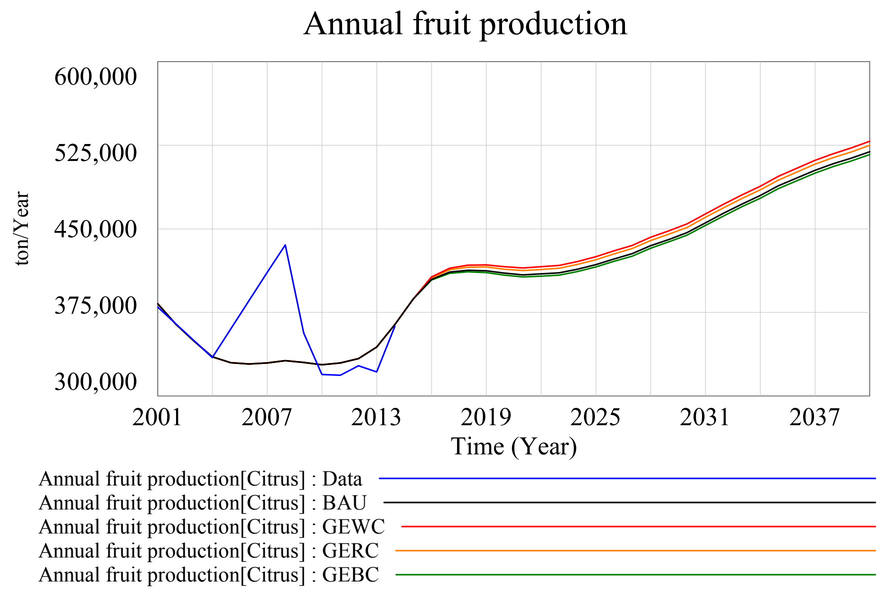

Figure D.6: Predicted citrus production for the Western Cape ($\sqrt{R} = -0.241$).

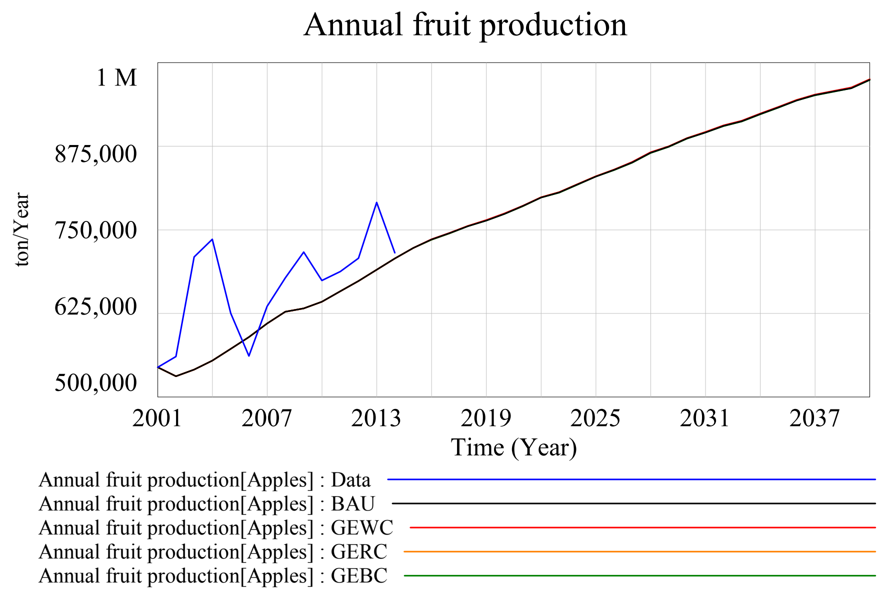

Figure D.7: Predicted apple production for the Western Cape ($\sqrt{R} = -0.287$).

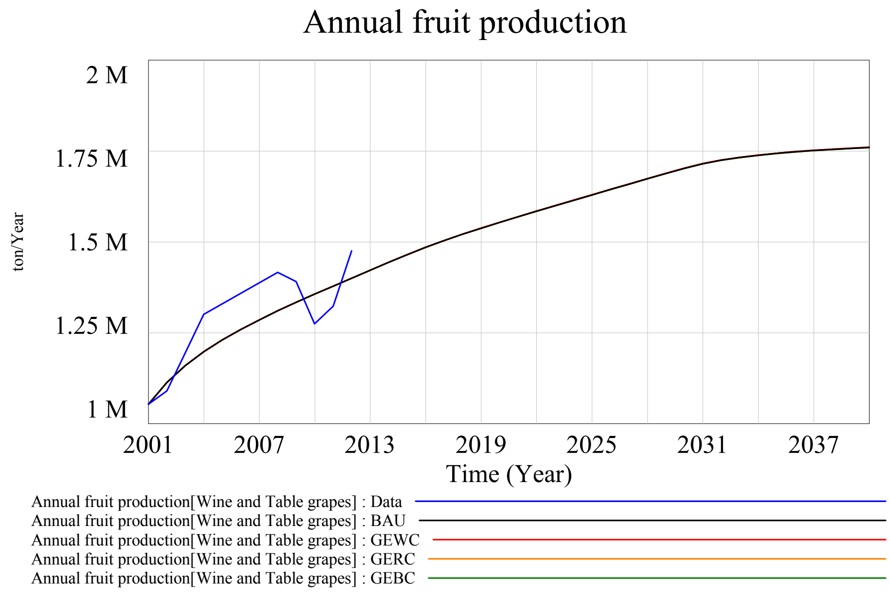

Figure D.8: Predicted wine and table grapes production for the Western Cape ($\sqrt{R} = 0.746$).

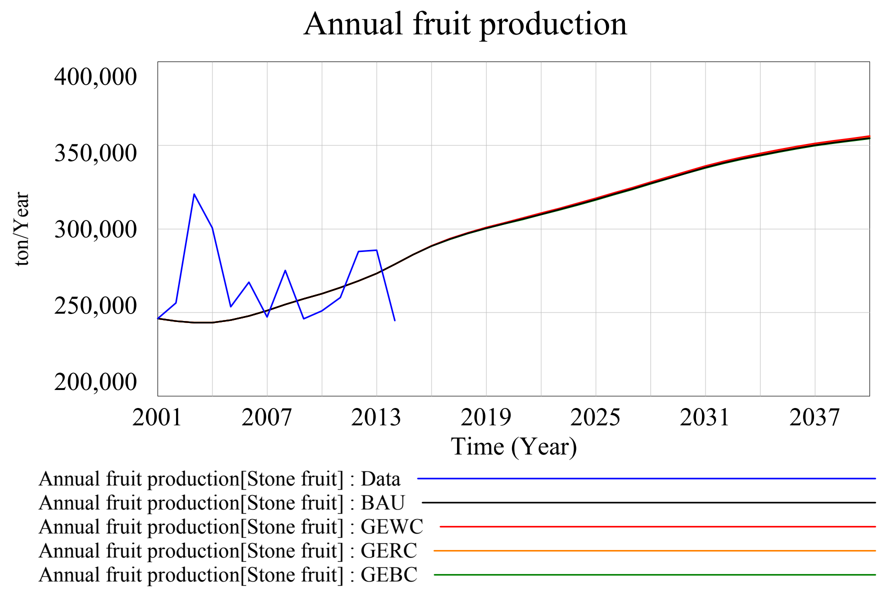

Figure D.9: Predicted stone fruit production for the Western Cape ($\sqrt{R} = -0.666$).

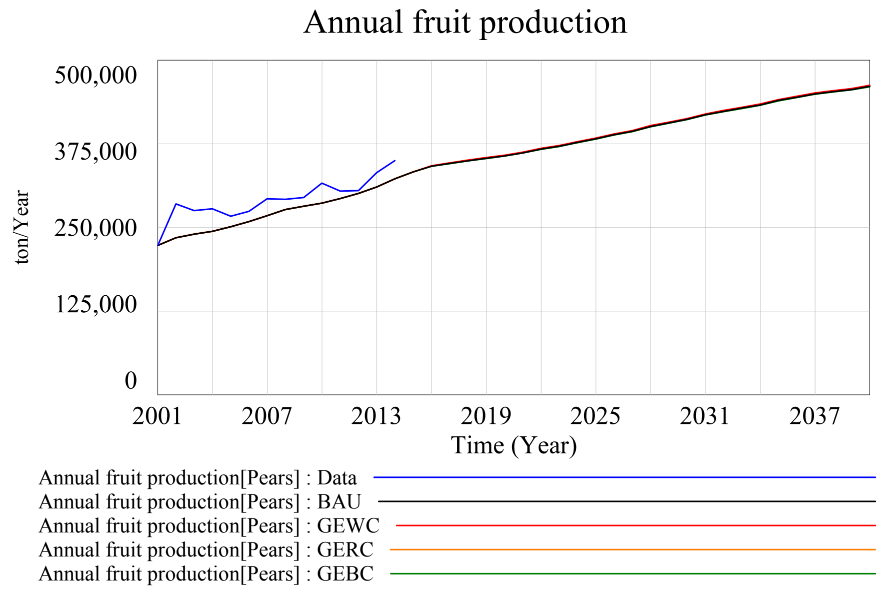

Figure D.10: Predicted pear production for the Western Cape ($\sqrt{R} = 0.290$).

Appendix E

Simulated results for production area used for each of the 10 different food crop commodities

The r-squared values ($\sqrt{R}$) for the production area graphs is the BAU scenario compared to historical data according to Vensim's statistical tool.

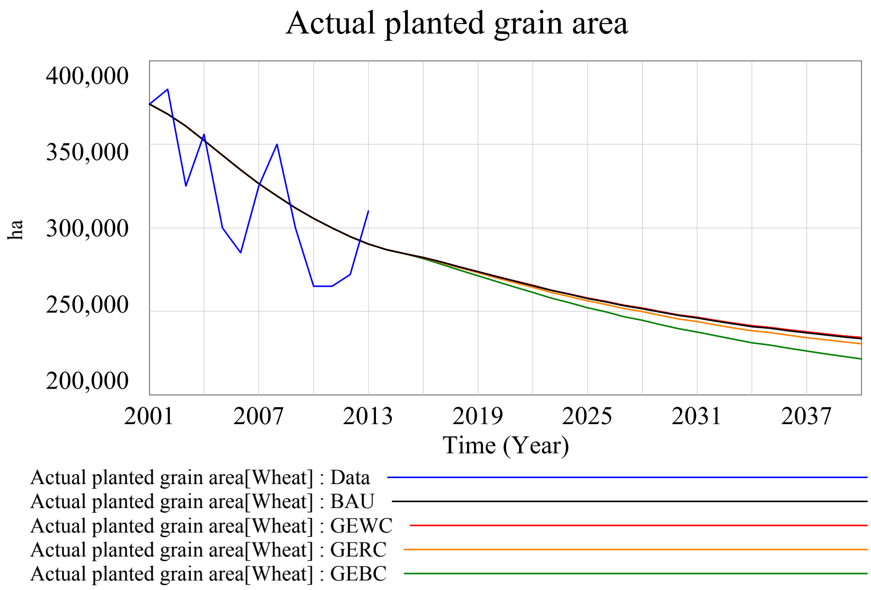

Figure E.1: Predicted wheat production area for the Western Cape ($\sqrt{R} = 0.446$).

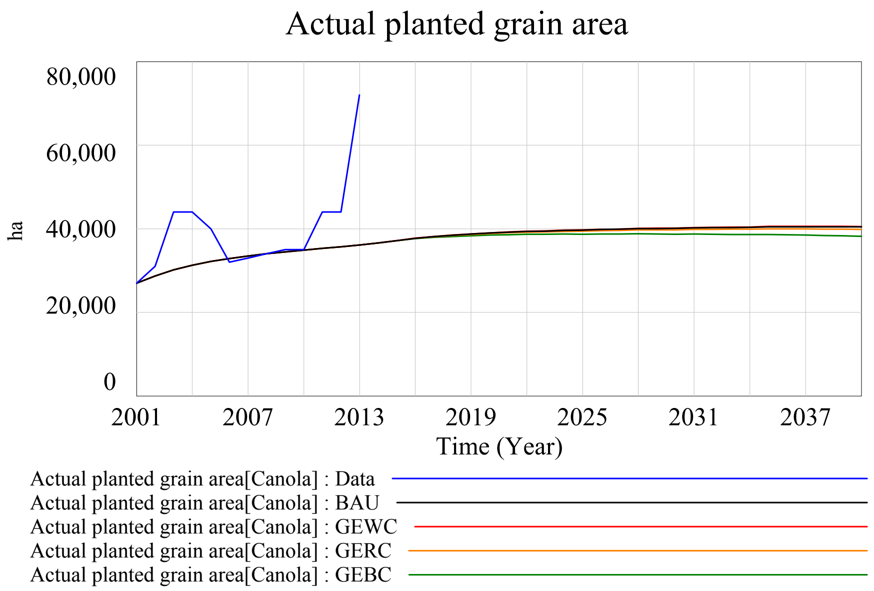

Figure E.2: Predicted canola production area for the Western Cape ($\sqrt{R} = -0.209$).

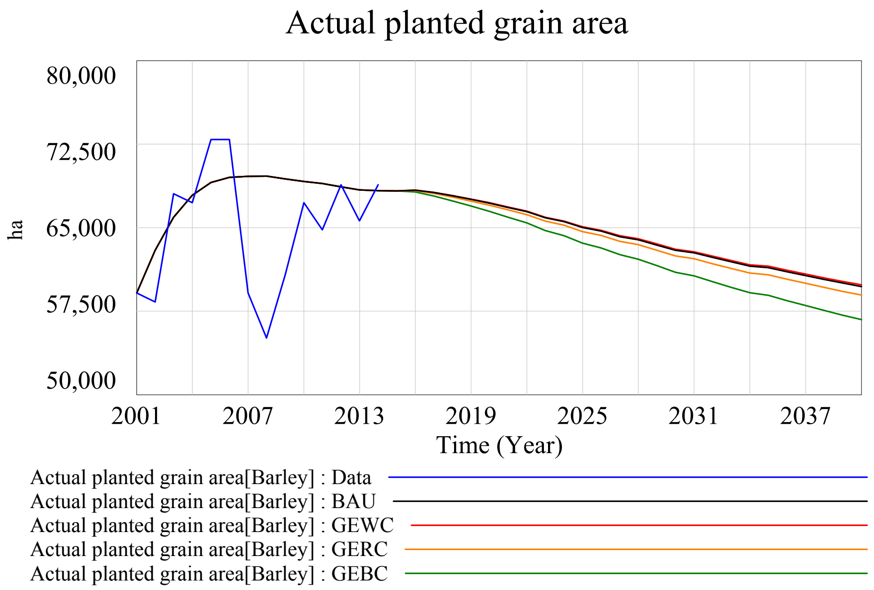

Figure E.3: Predicted barley production area for the Western Cape ($\sqrt{R} = -0.183$).

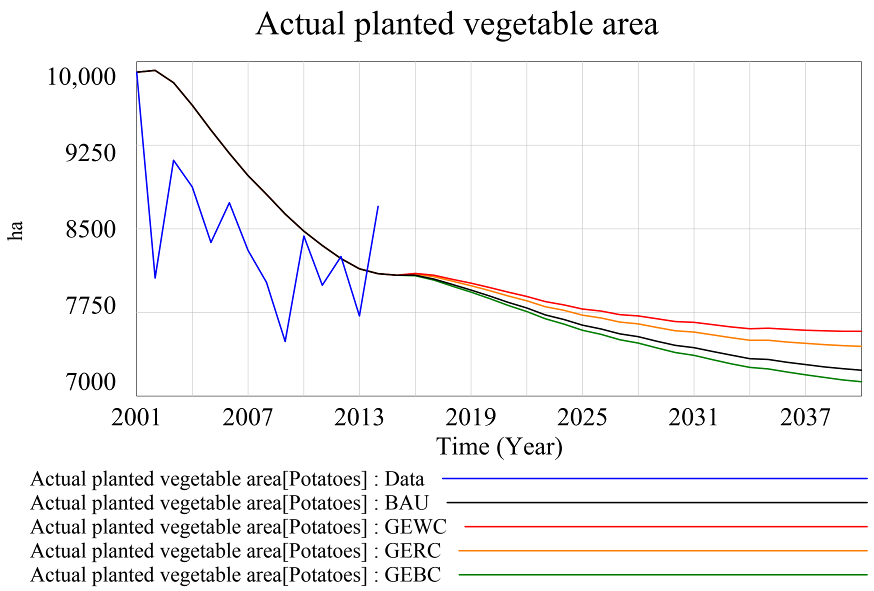

Figure E.4: Predicted potato production area for the Western Cape ($\sqrt{R} = -0.771$).

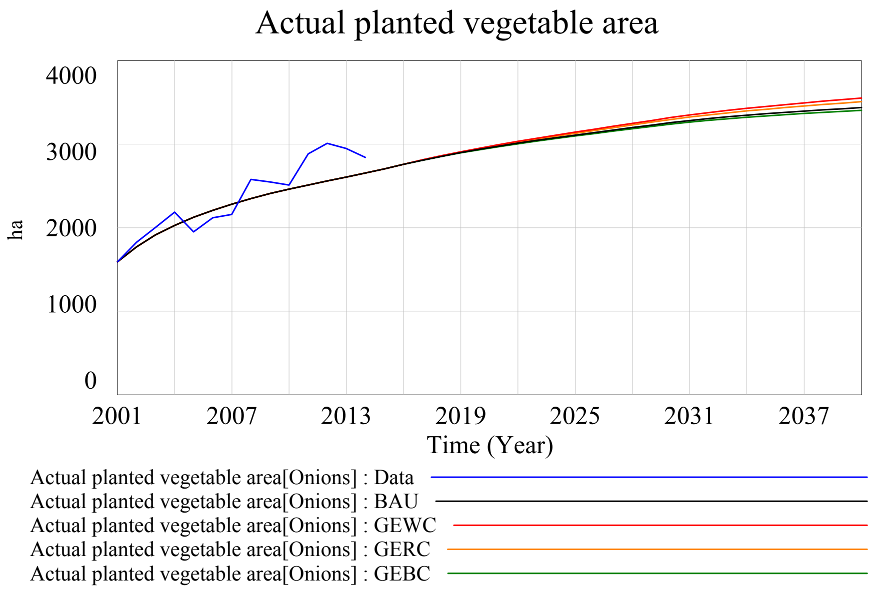

Figure E.5: Predicted onion production area for the Western Cape ($\sqrt{R} = 0.754$).

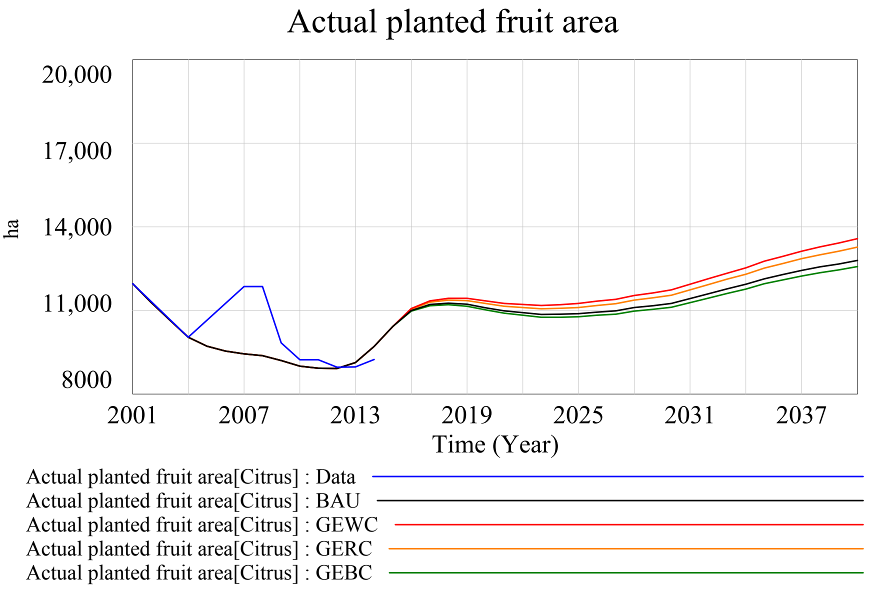

Figure E.6: Predicted citrus production area for the Western Cape ($\sqrt{R} = 0.119$).

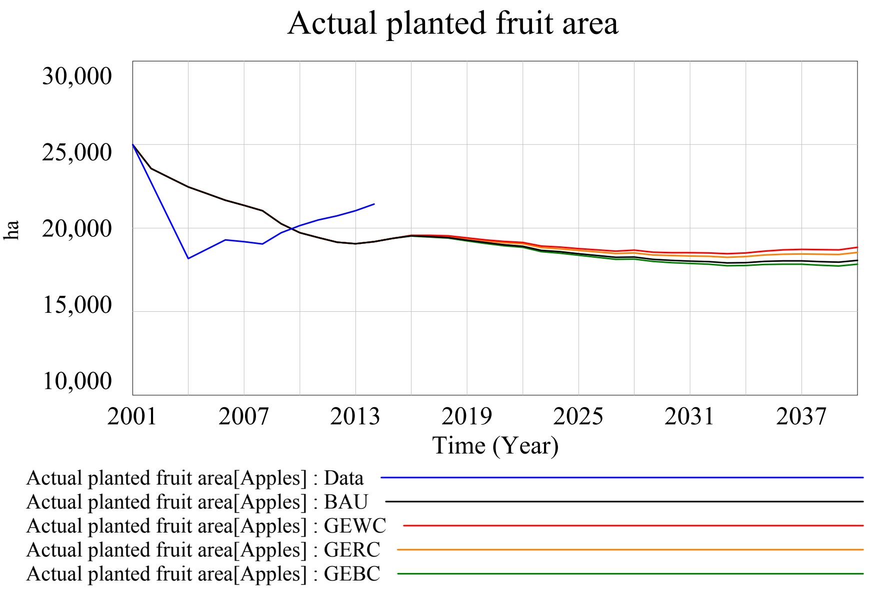

Figure E.7: Predicted apple production area for the Western Cape ($\sqrt{R} = -0.401$).

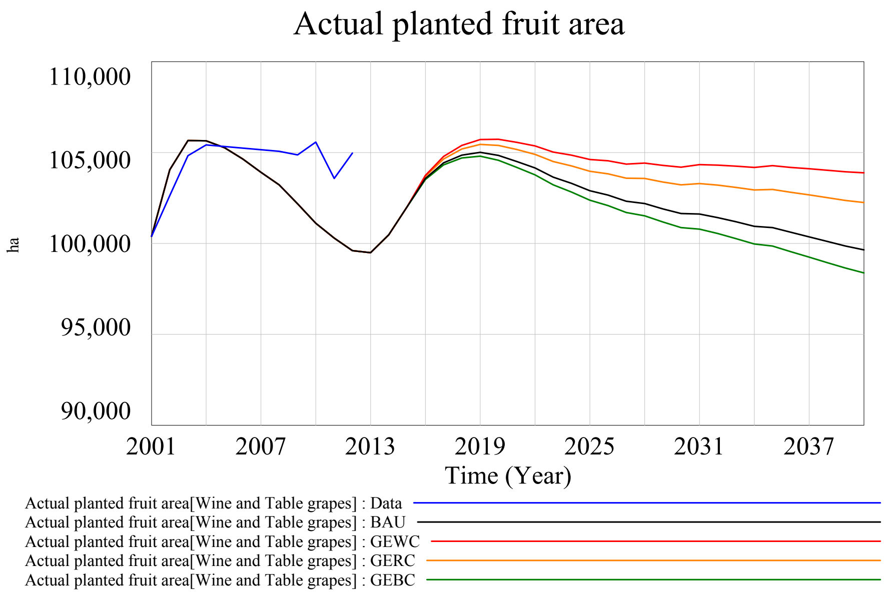

Figure E.8: Predicted wine and table grapes production area for the Western Cape ($\sqrt{R} = -2.18$).

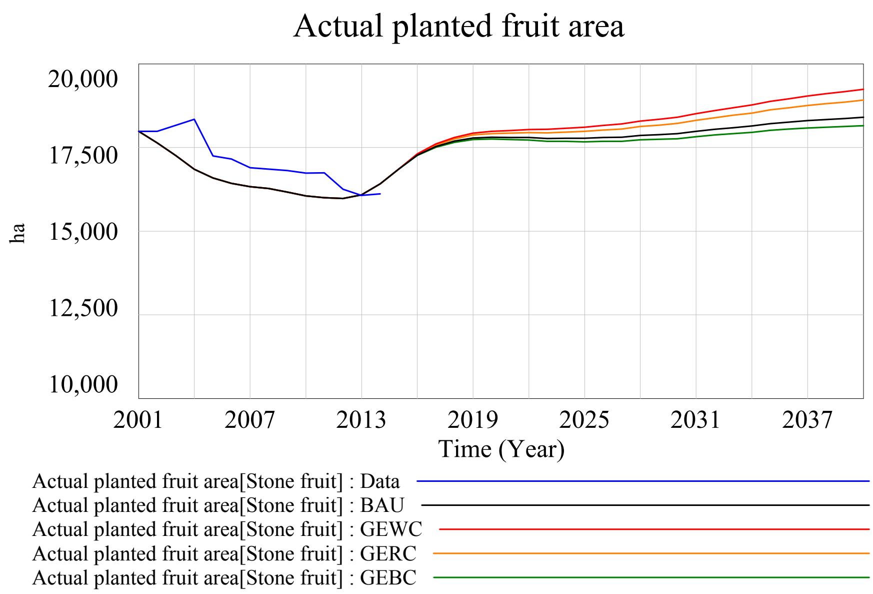

Figure E.9: Predicted stone fruit production area for the Western Cape ($\sqrt{R} = 0.157$).

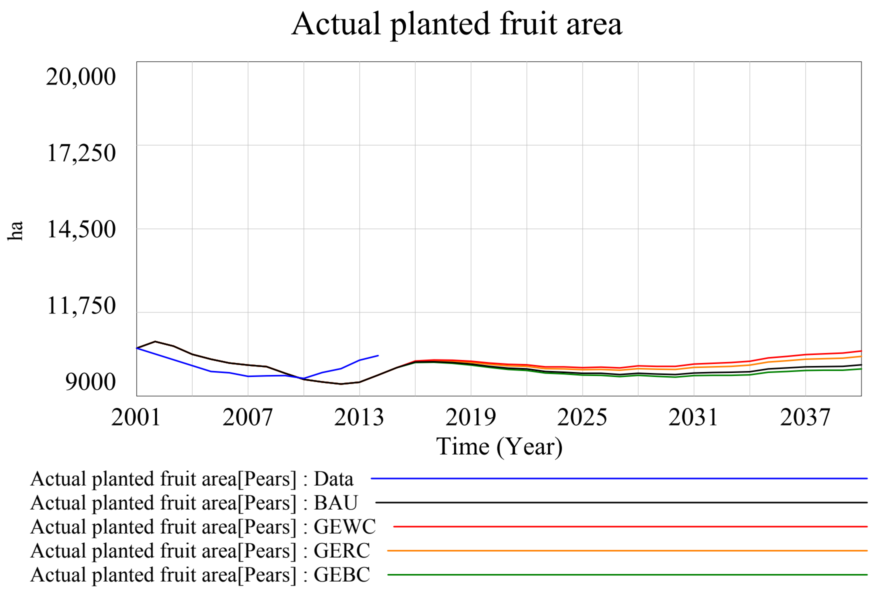

Figure E.10: Predicted pear production area for the Western Cape ($\sqrt{R} = -0.742$).

Appendix F

Simulated price results for each of the 10 different food crop commodities

The r-squared values ($\sqrt{R}$) for the price graphs is the BAU scenario compared to historical data according to Vensim's statistical tool.

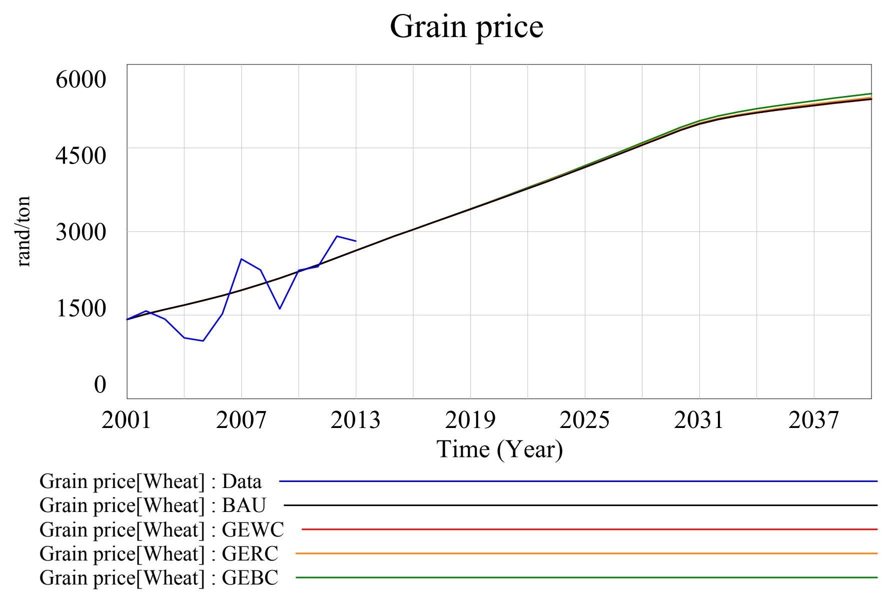

Figure F.1: Predicted wheat price for the Western Cape ($\sqrt{R} = 0.625$).

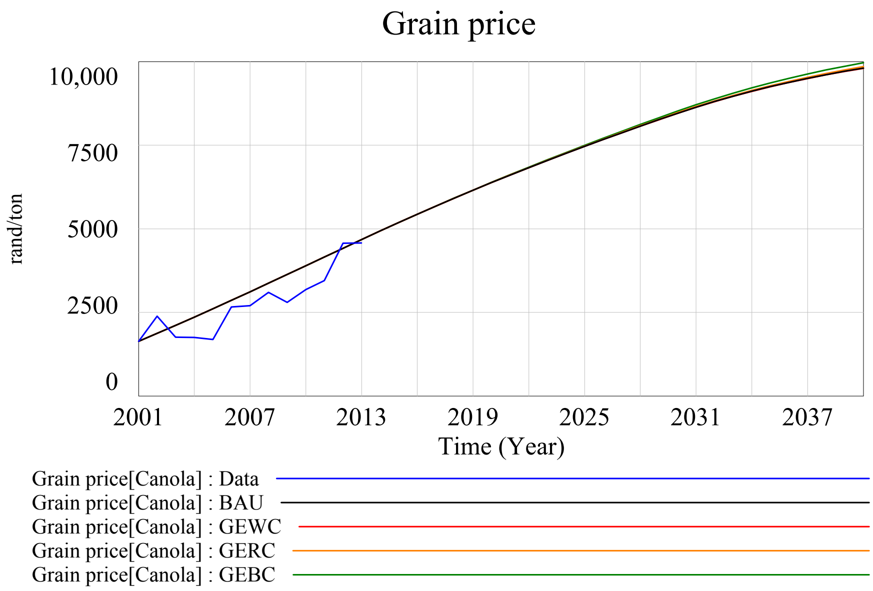

Figure F.2: Predicted canola price for the Western Cape ($\sqrt{R} = 0.697$).

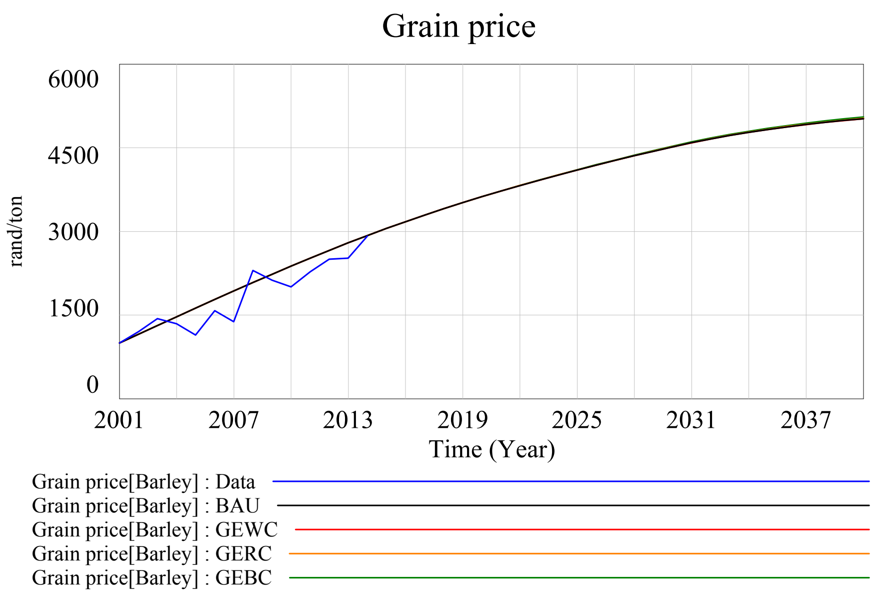

Figure F.3: Predicted barley price for the Western Cape ($\sqrt{R} = 0.802$).

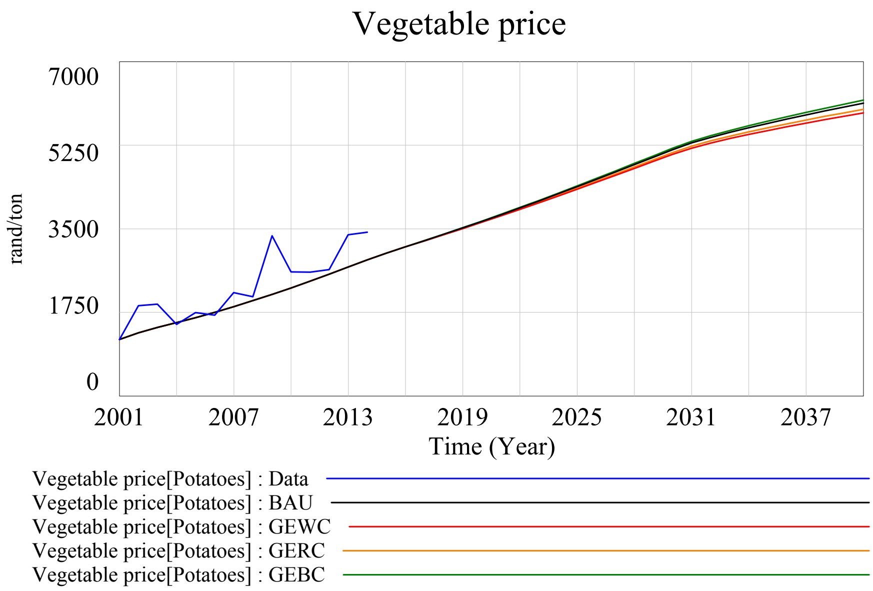

Figure F.4: Predicted potato price for the Western Cape ($\sqrt{R} = 0.539$).

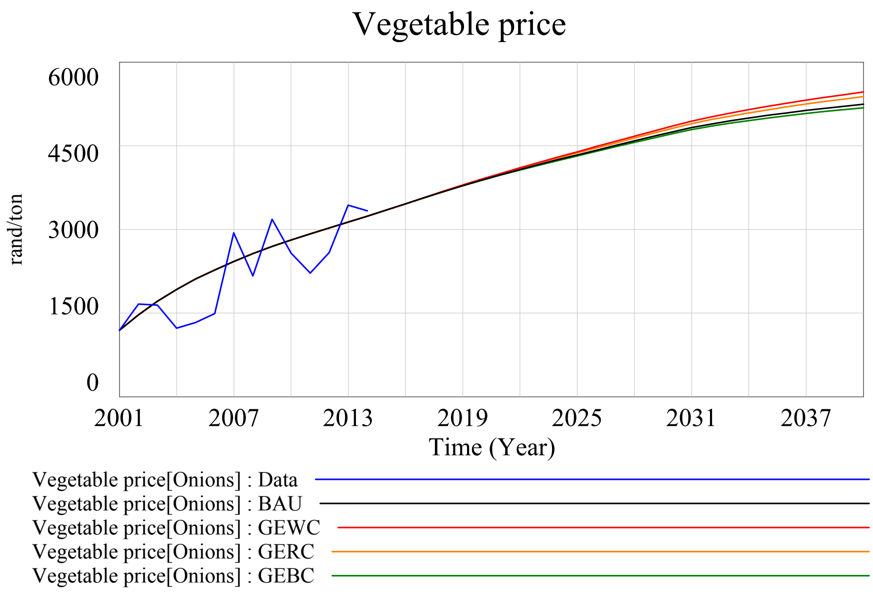

Figure F.5: Predicted onion price for the Western Cape ($\sqrt{R} = 0.614$).

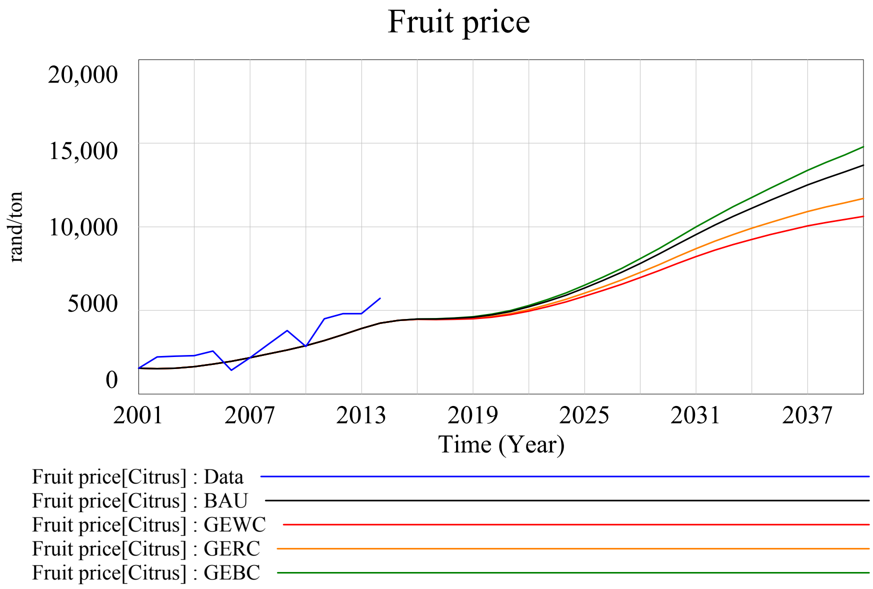

Figure F.6: Predicted citrus price for the Western Cape ($\sqrt{R} = 0.562$).

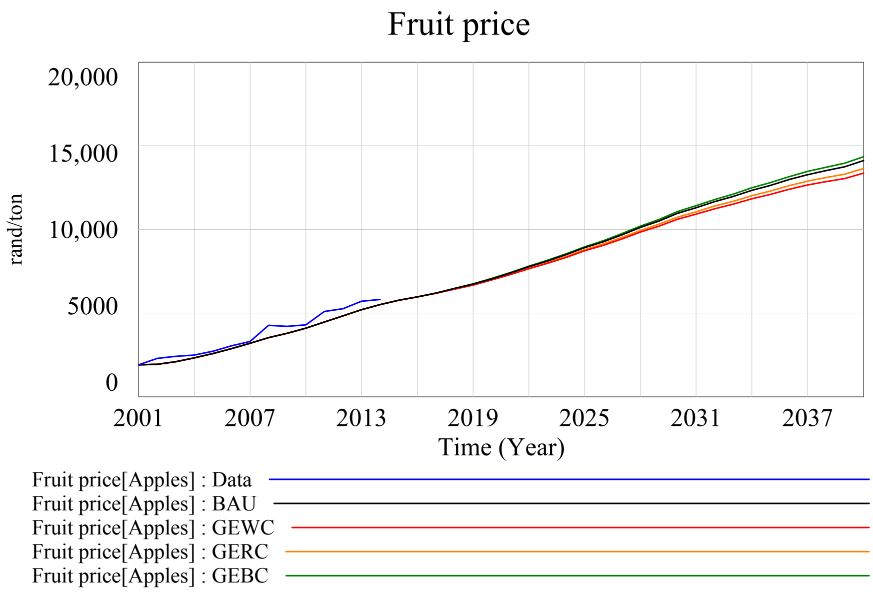

Figure F.7: Predicted apple price for the Western Cape ($\sqrt{R} = 0.917$).

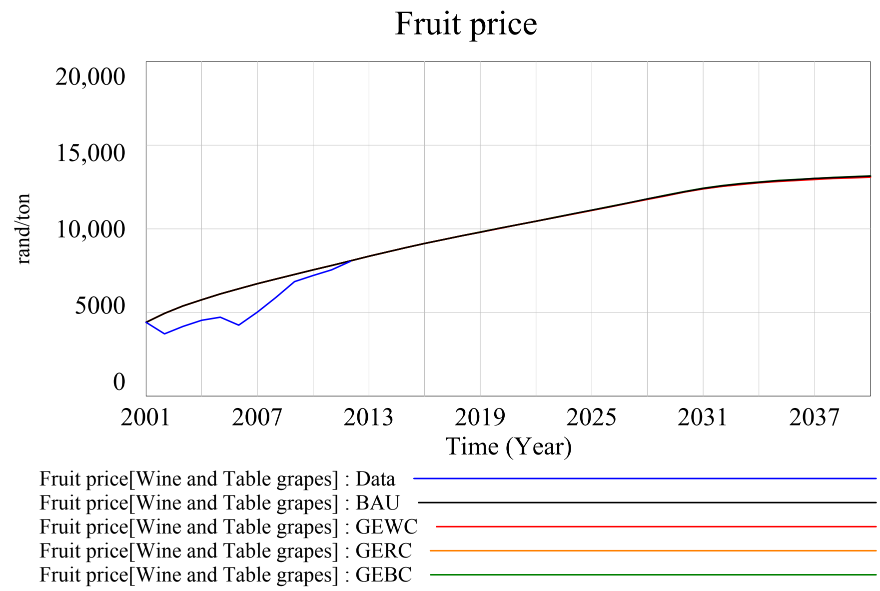

Figure F.8: Predicted wine and table grapes price for the Western Cape ($\sqrt{R} = 0.3759$).

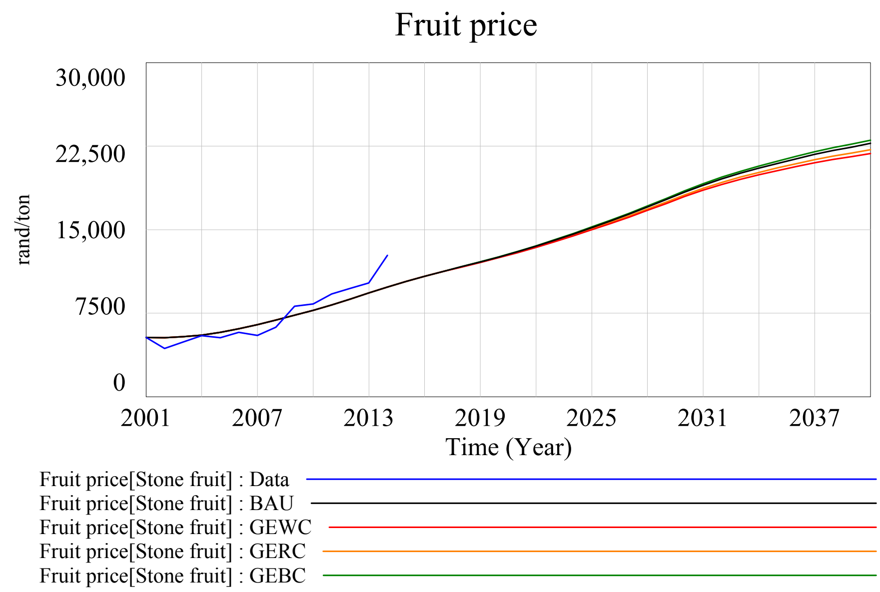

Figure F.9: Predicted stone fruit price for the Western Cape ($\sqrt{R} = 0.819$).

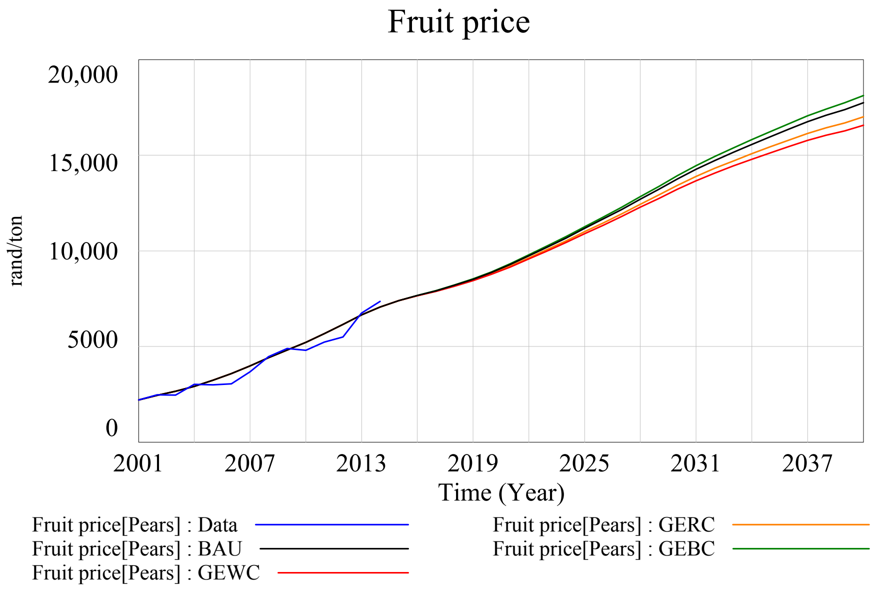

Figure F.10: Predicted pear price for the Western Cape ($\sqrt{R} = 0.960$).