A system dynamics approach to understand the implications of a green economy transition in the Western Cape Province of South Africa

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Abstract

Transitioning to a green economy presents opportunities and challenges for not only national governments, but also provincial and local governments. Within the South African context, a green economy transition is recognised as one of the key pathways towards achieving an environmentally sustainable, resource efficient, low-carbon economy, and a just society. For the Western Cape Province of South Africa, several sectors have been identified as capable of playing a key role in the government's effort to transition towards a green economy and becoming one of the leading green economic hubs of Africa. To achieve this transition, however, requires trans-disciplinary, integrated approaches to manage and plan the identified sectors. Using system dynamics, this paper developed a Western Cape Green Economy Model (WeCaGEM) to investigate the complexity involved in response to a green economy transition in the Western Cape Province. The model specifically focusses on green economy investment efforts in water, agriculture, transport infrastructure, renewable energies, energy production, carbon mitigation, and public services. The preliminary baseline results aim to validate simulated results with historical data. Future development of the model will involve validation with experts, establishing plausible or planned scenarios with experts and analysing green economy investment scenarios.

Keywords: *Green economy; Western Cape; South Africa; System Dynamics*

1 Introduction

Almost four decades after the World Commission on Environment and Development (WCED) defined sustainable development as "*development that meets the need of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987), the challenges, successes, failures and emerging problems concerning sustainable development are still at the forefront of international and national forums. The world today has unparalleled sophistication in the interventions, technologies and expertise available to address the many complex challenges that humanity face and to ensure intergenerational justice. However, numerous examples of shortfalls in terms of sustainable development are evident; the World Bank reports that carbon dioxide emissions continue to surge to unprecedented levels – global emissions in 2013 are estimated to be 36 billion tonnes, a 51 percent increase since 1990 (The World Bank, 2014). Another example sees that almost 27 percent of countries are "seriously off track" with their progress toward halving the proportion of people living without sustainable access to safe drinking water (The World Bank, 2014). In addition, phenomena like the global urban population growth outpacing the global rural population highlights the unremitting need to find innovative solutions to address and support sustainable development (UNEP, 2011b).

Aside from the vast number of methods and ways that have been developed to focus on the complex issues and 'wicked' problems concerning sustainable development, there are also developmental, scientific and economic improvement initiatives to address the multitude of crises that the world faces in terms of climate, biodiversity, fuel, food, water and global finances. One initiative that aims to bring forward a new economic paradigm in which "*material wealth is not delivered perforce at the expense of growing environmental risk, ecological scarcities and social disparities*" is the idea of a 'green economy' (UNEP, 2011a). Since Pearce et al. (1989) introduced the concept of a 'green economy" the notion, and the advantages and potential that it holds in terms of sustainable development, poverty eradication, and economic and social justification, has moved from specialist environmental discussions to the political mainstream (UNEP, 2011a). UNEP (2011b) defines a green economy as "*an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*". The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) further describes a green economy as one that emphasizes "*environmentally sustainable economic progress to foster low-carbon, socially inclusive development*". From these definitions it is evident that the relationship between the concept of a green economy and sustainable development lies in that a 'green economy' is a tool that can be utilized to assist and support sustainable development and poverty eradication efforts (UNECE & UNEP, 2011).

Since the introduction of the concept of a 'green economy', the demand for a 'green transition' is increasing. UNEP (2011b) and Musango et al. (2014a) demonstrate that the transition towards a green economy need not dampen economic activity and growth. UNEP (2011b) stresses three key enabling conditions that will support the transition towards a green economy: (i) deploying public and private investment in areas that are key towards transitioning to a green economy, (ii) sustainable forestry and ecological friendly farming, and (iii) providing guidance on policies to achieve the shift towards a green economy. The successful, sustainable transition towards a green economy thus demands a shift in socio-technical systems to arrive at a (not so distant) future state that allows for a sustainable approach to resource utilisation and ensures intergenerational justice (Markard et al., 2012).

Within South Africa, the government is increasingly recognizing the need to transition towards a green economy (DEA and UNEP, 2013; Musango et al., 2014a). Since the first Green Economy Summit that took place in South Africa in 2010[1], a number of initiatives relating to the green economy have emerged throughout the country at national, provincial and local governments. The drivers to a green economy transition include among others: (i) the need to move towards low carbon economies due to global climate change; (ii) increasing scarcity of material resources; (iii) rising awareness and threats of peak oil, food, water and financial crises; (iv) intergenerational justice; and (v) vulnerability of the economy to these factors (Lorek and Spangenberg, 2014).

An emerging literature is investigating various aspects of green economy transitioning. For instance, Law et al. (2015) developed a framework for assessing green economy transition in tourism destination, with specific focus in Bali, Indonesia. Doval and Negulescu (2014) utilized a survey to establish a model on the implications of green investments particularly for businesses in Romania. The key implications that they found were: (i) the formation of a new market; (ii) stability of small-medium enterprises; (iii) development of new polices targeting low carbon transition in order to maximise the value of green investments. The study by Musango et al. (2014a) is noteworthy in that it was the first in South Africa to develop an integrated system dynamics model to examine the transition to a green economy. They showed that green economy interventions could result in a low carbon transition, utilize resources efficiently and create additional jobs without necessarily slowing the economy. In addition, Musango et al. (2014b) specifically examined the green economy transition of the electricity sector in South Africa based on the South Africa green economy model. However, the limitation of the studies of Musango et al. (2014a; 2014b) is that the analyses were undertaken at a national level; yet, many of the green economy investment interventions are taking place at provincial and local government levels. Further, the provincial and local governments decision-makers are interested in understanding how much investments would be required to reach their planned targets, or whether their planned investments would achieve their planned targets, similar to the GETS scenario in Musango et al. (2014a).

This paper thus follows a similar conceptual framework utilized for the South Africa Green Economy Model (SAGEM) that was developed (Musango et al., 2014) to investigate the implications of green economy investments in the Western Cape Province of South Africa.

2 Description of the case study: Western Cape Province

The Western Cape Province is the fourth largest of the nine provinces in South Africa, both in terms of area and population. It covers an area of 129 370 km^2 and is home to approximately 6.1 million people (STATS SA, 2014).

The central emphasis of the transition to a Green Economy in the Western Cape Province primarily arises from the national policy response to the National Climate Change Response White Paper (DEA, 2011). The strategic priorities outlined in this document provide the direction of action and responsibility for the different levels of government. Section 10.2.6 of the National Climate Change Response states that: "*Each province will develop a climate response strategy, which evaluates provincial climate risks and impacts and seeks to give effect to the National Climate Change Response Policy at provincial level*" (DEA, 2011). In

[1] http://www.environment.gov.za/sites/default/files/docs/greene_conomy_summit.pdf.

response to this, the Provincial Government created the Western Cape Green Economy Strategy Framework with growth in green investments and market opportunities at the core of the strategic framework (Western Cape Government, 2013). According to the Strategy, the Western Cape Province aims at positioning itself as the lowest carbon province in South Africa and the leading green economic hub of the African continent. Five drivers that are identified for transitioning to a green economy are as follows (Western Cape Government, 2013):

- Smart living and working: Creating opportunities through less resource intensive living and working environments and consumption patterns.

- Smart mobility: Investment, job and enterprise opportunities created through reduced resource intensity of mobility and smarter mobility systems.

- Smart ecosystem: Enhanced water and biodiversity preservation, and expanded infrastructure, tourism, livelihood and job opportunities created through better managed ecosystems

- Smart agriproduction: Livelihood and market opportunities created through enhancing the competitiveness and resilience of our agricultural and food economies

- Smart enterprise: Investment, business and job opportunities created by establishing the Western Cape as a globally recognised centre of green living, working, creativity, business and investment.

Whilst the strategy is an attractive mode for transitioning, it remains the responsibility of the municipalities to plan and respond to climate change amidst the demanding challenges that they have to deal with. These challenges include, among others, limited skill development and capacity at a local level, persistent short-term needs diminishing already limited funds, and the inability to predict with any certitude the necessary adaptions for future conditions (South Africa LED Network, 2010). All of which form the setting of the emerging need to prepare municipalities towards a green economic transition, which is evidently a great challenge.

Informed by the strategy, this paper specifically focuses on water, agriculture, transport infrastructure, renewable energies, energy production, CO_2 emissions, and public services as a starting point for investigation.

3 Methodology

Most of the problems that are currently faced such as the depletion of natural resources and global climate change result from unintended consequences of past actions or interventions. Similarly, policies and strategies that are undertaken to solve these problems may fail of even pave the way of other problems. Effective decision-making thus requires a systems thinking approach that can be able to account the dynamic complexity of the problems been faced. The need for green economy transitioning is not an exception as it arises due to the recognition of a global polycrisis (Swilling and Annecke, 2012; Lorek and Spangenberg, 2014).

System dynamics is an integrated modelling approach that enables the understanding of complex real world problems over time in order to guide decision-making for achieving sustainable long-term solutions. Jay Forester developed system dynamics in the 1950's where he first applied it to analyze industrial business cycles (Forrester, 1961). Since then, it has been applied to address problems from various fields of studies relating to economy, society and environment. For instance, in his book, Ford (2010) illustrates cases for the application of system dynamics in modeling environmental issues. Forrester (1969) and Forrester (1971) applied it in analyzing socio-economic dynamics. Several authors have utilized it in sustainability issues including among others: water resource management (Winz et al., 2009), energy planning (Naill, 1992, Qudrat-Ullah, 2013); urban planning (Fong et al., 2009); and climate change mitigation (Bassi and Baer, 2009). It is also being utilised to investigate issues relating to a green economy transition (UNEP, 2011; Musango et al., 2014a; Musango et al., 2014b).

System dynamics makes use of four basic building blocks, namely: stocks, flows, auxiliaries and constants (Sterman, 2000; Musango et al., 2014b). Using these basic building blocks, it is possible to capture the dynamic complexity and represent different viewpoints. This is very relevant when it comes to green economy issues that require accounting for economy, society and environment sub-systems. Further, it is possible to develop scenarios in order to test the implications of green economy interventions.

4 Model description

This section outlines the structure of the model that was developed to examine the implications of a green economy transition in the Western Cape Province of South Africa. The integration of the concept of a green economy transition into a formal model calls for the amalgamation of economic and physical dimensions of the social, economic and environmental systems being analyzed. This analysis occurs across the different sectors of the province, following the dynamic nature of the green economy concept.

4.1 Model boundary

The key variables that were considered essential in catalysing the green economy transition in the Western Cape Province of South Africa were calculated endogenously in the model. An array of stocks, flows and variables, among which, are the variables of the prioritized areas of interest based on the research aim and problem definition. These include aspects such as: Water Conservation, Sustainable Agriculture, Sustainable and Efficient Transport Infrastructure, Renewable energies, Energy Production, CO_2 emissions, and Sustainable Public Services. Broadly these focus areas can be categorized into the three development spheres of sustainable development (see

Table 1), which aim to incorporate and define the model boundary in terms of where the sub-models fit within a green economy shift. The key variables in each sub-model were used as indicators for analyzing the model transition to a green economy within the Western Cape Province.

Table 1: Modules and development spheres for the Western Cape Green Economy

Society Sphere	Environment Sphere	Economy Sphere
Population 1. Population	**Land** 8. Provincial Land 9. Agricultural Land	**Production** 21. GDP 22. Agricultural yield 23. Agricultural Production
Education Sector 2. Education	**Water** 10. Water Demand	
Health Sector 3. Healthcare	**Emissions** 11. Emissions (Agriculture) 12. Emissions	
Employment 4. Employment	**Energy** 13. Fuel Demand 14. Electricity Demand 15. Nuclear Power 16. Pumped Storage Power 17. Solar PV power 18. Wind Power 19. Gas Power 20. Modal Energy Split	
Public infrastructure 5. Transport 6. Live Vehicles 7. Road Infrastructure		

4.2 Aggregate causal loop diagram

Figure 1 shows an aggregate causal loop diagram (CLD) to describe the relationship between the various aspects of a green economy that were investigated. The CLD gives a very brief overview of the model interactions, which were broken into a variety of specific and detailed sub-models.

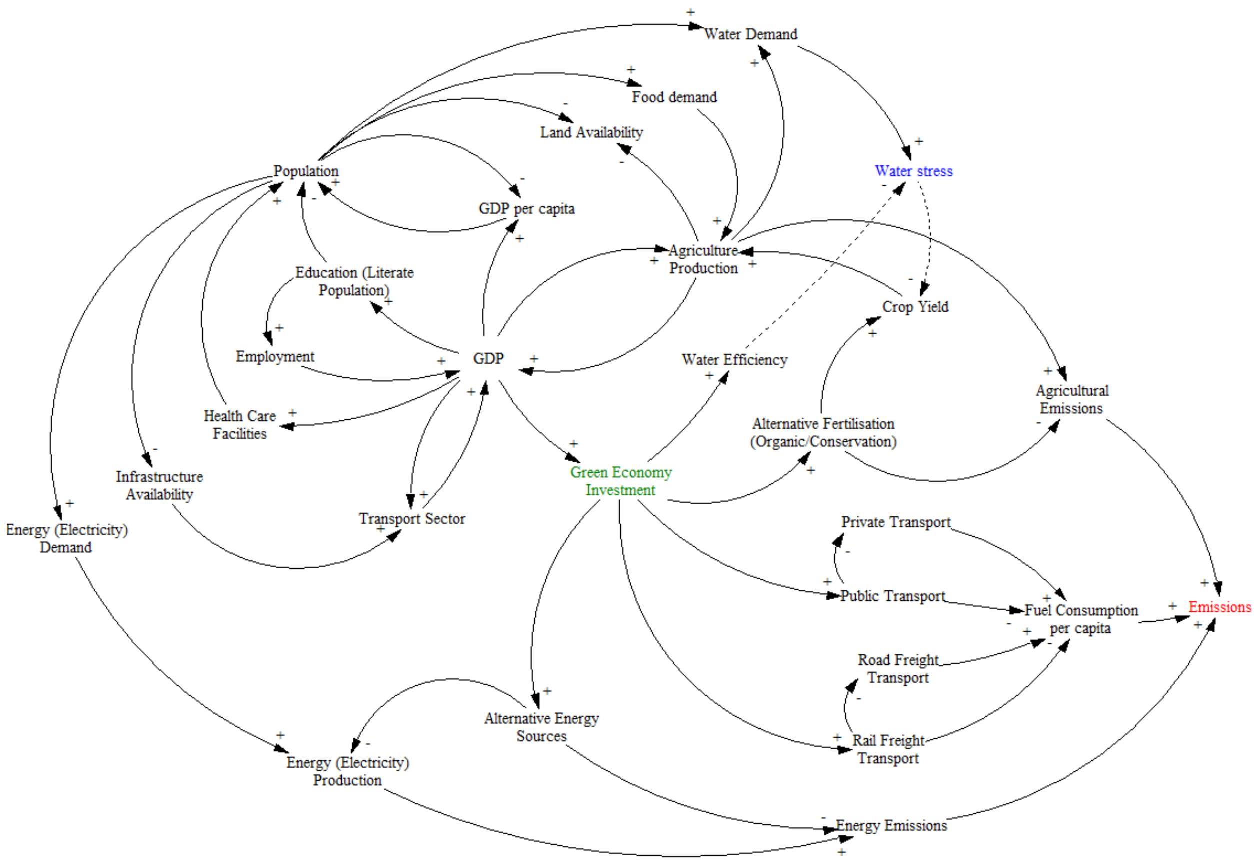


Figure 1: Aggregate causal loop diagram

In a broad sense the CLD indicates how an increase in population will increase water, food and electricity demand. An increase in population will also decrease land availability, GDP per capita, and infrastructure availability. The increase in water demand will increase the water stress indicator, which directly influences the agricultural crop yield and agricultural production. Food demand influences agricultural production, while an increase in agricultural production is likely to cause a decrease in land availability. Agricultural production will improve the GDP, which will in turn make more funds available to invest in education, contributing to better employment rates and once again influencing the GDP positively. A larger GDP will ensure that there is sufficient growth in the transport sector and health care facilities. A growing transport sector will positively contribute to the GDP while healthcare facilities will reduce mortality rates in the population.

Depending on the green economy (GE) investment strategy, a larger GDP is likely to lead to growth in the green economy investment scenario, which will increase water efficiency and lead to a reduction in the water stress indicator. The GE investment will also encourage the use of alternative fertilization techniques that can better the crop yield to increase agricultural production and lower the agricultural emissions. The GE investment will focus on shifting from road to rail freight and from private to public transport, which will decrease the fuel consumption per capita and lead to lower emissions in the transport sector. The use of alternative fuel and energy supplies will also be supported by GE investment and will decrease emissions from the energy sector.

4.3 *Model settings*

The model simulates a 40-year period, equating to a time horizon of 2001 to 2040. The model was simulated using the time unit of years. The Euler method was selected for numerical integration purposes: the level of data uncertainty, speed requirements and lack of specificity-requirements warranted selecting Euler over Runge-Kutta. The model was constructed and simulated using Vensim DSS (Ventana Systems, 2013).

4.4 *Sub-models*

This section describes the simulation model by introducing the sub-models that were developed. The model consists of 23 sub-models. These key sub-models are described in the sections that follows, surfacing the assumptions (and some of the limitations) associated with each part the sub-model.

4.4.1 Population sub-model

The population sub-model represents the population of the Western Cape Province. The population is categoris`d according to sex (male and female) and age groups. The sub model is used to estimate the population through the influence of dynamic factors such as fertility rate, net migration, and death rate. Fertility rate influences births, which increases population. Fertility rate is dependent on the effects of economic conditions and contraceptive prevalence (affected by literacy rate) in the province. Births are dependent on the total fertility rate, sexually active female population, and the childbearing age specific fertility rate. Childbearing age was defined as being between age 15 and 49. The population also increases through net migration, which is dependent on the Western Cape population itself and a migration rate. Deaths however decrease the Western Cape population. Deaths are influenced by the life expectancy of the residents of the province. Life expectancy is affected by income per capita and how that influences normal life expectancy.

Population itself also affects are factors in other sub-models. For example the age groups determine the amount of students in school and the adult literate population. If the population increases and access to education remains constant, then the average adult literacy rate of the population will decrease. This will result in a decrease in contraceptive use in the province and result in more births, which then in turn increases the population.

4.4.2 GDP sub-model

The GDP sub-model estimates and tracks the growth in the provincial GDP over time. Due to a lack in data and model outputs the GDP uses the baseline GDP of South Africa as determined in SAGEM and is factored down and calibrated to fit the existing GDP recordings. Whilst this may be considered a crude form of modeling, the variables used from this sub-model are predominantly exogenous, thus making the sub-model in its entirety somewhat exogenous as well. The major variables considered in this module are those of Relative Real GDP and the Relative Real GDP per capita, both used as growth factors in other sub-models.

4.4.3 Education sub-model

The education sub-model is based on the South African educational system, which stipulates that a pupil can be classified as literate after a minimum of seven years of education. The system further makes education compulsory up until grade 9, indicating that everyone will have a minimum of nine years General Education and Training (GET). As part of the GET and Adult Basic Education and Training (ABET) everyone should have basic reading and numeracy skills by the age of 15 and would then be considered literate. The reality is however that not all children in the school going age (generally considered to be 6 to 14 years of age) attend school, due to financial constraints and a lack of space in the school system capacity caused by under investment.

The education sub-model considers factors influencing the school entrance rate, like willingness to go to school, population in school going age and available school capacity. The model then simulates dropout rate and grade 9 completion rate based on historic data and average time taken to complete a grade and education expenditure. The model uses the population sub-model to determine the literate young adult population and literate initial adult population, which is used to simulate the average adult literacy rate of the Western Cape. The average adult literacy rate influences a number of factors in various other models, like the use of contraceptives to influence birth rates, the awareness of water conservation to decrease water usage per capita and employment rates.

4.4.4 Health sub-model

The health sub-model for Western Cape healthcare facilities aims at representing the access to basic health care based on government expenditure. This sub-model provides variables indicating the access to basic health and follows the number of healthcare facilities in working order as the stock. Health care facilities were broken into three subscript levels with public hospitals (including national central, provincial tertiary, regional, district and specialized hospitals), primary healthcare facilities (including clinics/community health centers, satellites, and mobiles) and private registered hospitals.

The one stock – Western Cape healthcare facilities – is increased by health center construction and decreased by health center disruption, which is influenced by the average lifespan of the facility. The factors influencing the construction of new health centers is the capital health expenditure allocated from the provincial government and the associated construction costs based on past and current projects. The total health expenditure from provincial government budgets was correlated to information gathered from National Treasury Budget reports. The proportion of total capital expenditure spent on the construction of new health centers was derived from the annual infrastructure payments from the health budget. The two main variables existing as performance indicators are the number of population per health center and the access to basic health care based on the area covered by the different health centers relative to total land.

4.4.5 Employment sub-model

Employment is a measure of the amount of people actively participating in the economy. Unemployed people do not create or add to the economy, nor do they support economic activity by paying for goods or services. The model differentiates between three different streams of employment, each represented by a stock: agriculture, usual industry and usual services. The stocks are each influenced by their respective net industry-hiring rate. The rate of hiring/firing in each respective industry is determined by the capital investment in each sector. Finally, the total employment in the Western Cape economy is estimated.

4.4.6 Road infrastructure sub-model

The road infrastructure sub-model aims to estimate the access to road infrastructure in terms of relative kilometers of functioning roads per hectare of land translating to the accessibility of road infrastructure. The sub-model consists of three stock; the first two being roads under construction and functioning roads, systematically illustrating the dynamics that exist in road infrastructure development. The major variable affecting the flow of starting to construct a road is the Budget attributed to road infrastructure and the average construction cost per kilometre of road. The third stock tracks the change in costs road maintenance per kilometre over time; this has a direct influence on road maintenance costs which then draws the required government expenditure on road infrastructure.

Starting construction increases the stock of roads under construction, once completed it moves to the stock of functioning roads where road depreciation and disruption occurs thus decreasing the stock over time. Road maintenance decreases the disruption to the roads by increase the average road life, however increases in heavy vehicle haulage over a certain amount decreases the average life. The relative kilometers of roads act as a measure of road access and are used in the greater transport sub-model.

4.4.7 Live vehicles sub-model

The live-vehicles sub-model aims at tracking the amount of live vehicles on the roads in the Western Cape each year. The total amount of live vehicles is sectioned into the subscripts: motorcars and motorcycles, mini-busses, busses, light duty vehicles and light load vehicles, trucks, and other vehicles. The sub-model consists of one stock, motor vehicles, which is increased by vehicles sales and decreased by vehicle disposal. Vehicle sales are derived from the desired vehicles relating to the population and desired vehicle ownership, which is influenced by GDP. On the other hand, the average vehicle life spans are different for the different vehicle sub-groups. The key variables utilized in the greater transport sub-model are the relative number of trucks on the road (relating to functioning road disruption), the total vehicle count for each year and the relative motor vehicles used as a growth factor.

4.4.8 Transport sub-model

The transport sub-model is used to estimate a number of variables ranging from the energy use for different transport sectors to the fuel demand and CO_2 emissions. The transport sub-model is categorized into three modes, namely: road, rail and air. These are further categorized based on whether the mode is dealing with the transportation of passengers or freight/goods/cargo commodities. The annual modal passenger travel distances are determined by the travel distances per vehicle type growing according to the relative kilometers of functioning roads and the relative real GDP. For private passenger trips and minibus taxis the live vehicle stock is used as the multiplying factor, yet for the other modes different population factors are used in conjunction with the average capacity of the vehicles to determine the passenger travel distances. The annual road freight haulage is determined in a similar manner, using the live vehicle stock for heavy vehicles and the average load for road freight haulers.

The rail sector for both passenger and freight modes are dependent mainly on the relative GDP and calibrated to fit collected annual data with the use of elasticity factors. The annual passengers carried by rail are also linked to the relative growth of the population and for the energy consumption was considered to be 100% electricity dependent as the majority of the cape Metrorail line is electrified. Similarly, air transport of both goods and passengers are determined by growing factors of relative population and GDP with elasticity factors to calibrate the output. The volumes of passengers and goods handled along with the distances they are transported are used to determine the energy use for the different transport modes as well as the resulting CO_2 emissions each year.

4.4.9 Land sub-model

The land sub-model represents the land use of the Western Cape Province. The model consists out of two models in total, namely provincial land and agricultural land. The provincial land model includes settlement land, invasive alien species land, livestock land, conservation land, agriculture land, and other land. Due to irrigation and rain restrictions only 19% of the Western Cape's total land is cultivatable; therefore agriculture land ("Land available for agricultural use") is limited to no more than 19% of total land for this model.

The agriculture land sub-model consist out of land used in the agricultural sector for; conventional, conservation, organic farming. It is assumed for this model that land for conservation and organic use can only be converted from conventional land. It is also assumed that conservation and organic land will never degrade back to conventional land once the decisions has been made to increase either one those two practices.

4.4.10 Water demand sub-model

The water sub-model is primarily used to estimate the water stress index, which has an influence on the production sectors. To estimate the water stress index the yearly available water supply and demand is required. The available water supply is calculated by taking precipitation, cross border inflows and water gains from restoration into account. In the case of the total water demand the domestic, municipal and production sectors are considered. The domestic and municipal water demand depends on per capita water demand, which in turn is affected by the education and wealth of the user. Production water demand is mainly dependent on the GDP of the Western Cape.

4.4.11 Energy sub-model

The energy sector looks exclusively at electricity and ignores other forms of energy that are not used for generating electricity. The electricity sector is categorized into electricity demand and electricity supply. Electricity supply consists of the different methods of generating electricity in the Western Cape Province namely, nuclear, pumped storage, natural gas, wind, and solar, and also electricity generation technology share. The aforementioned technologies are considered to be the most suitable for implementation in the province. Electricity generation from coal is not included, as no coal-fired power stations are in operation in the province and there are no future plans to add any coal-based power stations. Wind energy and solar energy are the only generation technologies seen as renewable energy technologies in this model. Electricity demand is calculated using the total provincial electricity consumption and the generation, transmission and distribution losses, giving a total electricity demand.

In reality, the electricity grids of the different South African provinces cannot be separated, as they are all part of one large national grid. Electricity produced by power stations in one province can be used by consumers in any other province, and the electricity demand in a province can be supplied by a combination of power stations in the other provinces. For the purpose of analyzing the Western Cape Province in isolation, the province is seen as having its own electricity grid. All the electricity that is generated by power stations within the province is assumed to supply only the demand of the province. If the province's electricity demand exceeds the supply, the needed electricity is imported from outside the province. This situation is normally the case, with the majority of South Africa's base load generating capacity situated outside the Western Cape.

The electricity generation technology share module estimates the proportion in which each technology contributes to the total electricity supply. Electricity demand is calculated by adjusting demand according to changes in GDP, population, green investment in energy efficiency, and electricity price. Electricity price is seen as an exogenous variable. This assumption is reasonable because the province has no control over the price of electricity. In South Africa, the electricity price is regulated by the National Energy Regulator of South Africa (NERSA).

4.4.12 Emissions sub-model

The air emissions module estimates CO_2 emissions from the different sectors. These sectors are categorized as emissions from electricity and non-electricity industry. The electricity sector includes emissions from coal, nuclear, pumped storage, hydropower and renewable resources. The non-electricity sector comprises of transport, agriculture, residential and industry CO_2 emissions. A Western Cape Scaling Factor is used where no data for the province has been collected previously. Therefore the South African data is scaled to fit the Western Cape profile. The annual CO_2 emission is endogenously determined in the modeling.

4.4.13 Agriculture yield sub-model

Agricultural yield is influenced by multiple factors such as agriculture capital and water stress levels in the province. The agriculture yield for each crop type is further affect by conventional, conservation, and organic farming practices. Organic farming has less CO_2 emissions per hectare than conventional farming, but yields also tend to be less than that of conventional farming.

4.4.14 Agriculture production sub-model

The agricultural production sub-model mainly focuses on food crops. The food crop considered were broken up in three main categories, namely: fruit, gain, and vegetables.

Table 2 lists the elements of each one of these three categories as well as the different farming practices that can be applied to each category. Conservation farming practices are not applicable to fruit farming, therefore any conservation land that is allocated to fruit will be regarded as conventional land and yield. Due to a lack of technology and significant capital investment, conservation farming is also not considered for vegetable farming.

Table 2: Food crop categories for agriculture production

Food crop category	Elements	Farming practises
Fruit	• Citrus • Apples • Wine and table grapes • Stone fruit • Pears • Other fruit	• Conventional • Organic
Grain	• Wheat • Canola • Other grains	• Conventional • Conservation • Organic
Vegetables	• Potatoes • Onions • Other vegetables	• Conventional • Organic

The land required of each type of food crop can be determined by using the average yield per hectare and population requirements of the Western Cape. For example, if the yield per hectare for apples increases and the population stays the same, then less area is required for apple production. Another example is when wheat yield per hectare decreases (due to water stress) then more area is required to provide wheat to the current population.

4.5 *Model verification and validation*

Model verification and validation is integral part of system dynamics modeling. Model verification entails checking and testing (i) dimensional consistency; (ii) sub-models and structures; (iii) appropriateness of combination of numeric integration method and step size; and (iv) all equations and inputs for errors (Pruyt, 2013). The developed model was verified using the System Dynamics Model Documentation and Assessment Tool (Martinez-Moyano, 2012).

On the other hand, validation corresponds to establishing confidence in the purpose and usability of the model (Barlas, 1996; Pruyt, 2013). There is no single test for validation and these can be categorized into: (i) direct structure tests; (ii) structure-oriented behavior tests; and (iii) behavior reproduction tests (Barlas, 1996; Pruyt, 2013). There is currently no historical data for the green economy intervention sectors that is available to properly utilize the behavior reproduction tests for most of the model variables. This was limited to some variables such as population and gross domestic production. Much of the validation done was mainly the direct structure tests and structure oriented behavior tests. It is expected that the model will be further subjected to expert opinion before undertaking scenario analyses.

5 Preliminary baseline results

For the purpose of this article only the business as usual (BAU) scenario is executed. The green economy investment (GEI) scenario analysis will only be executed once validation with experts has been undertaken and suggestions on plausible or planned scenarios and targets are established. The BAU scenario can be described as continuing with current practices and regulations until 2040.

BAU sets the baseline for the whole model and estimates how the Western Cape is functioning across all sectors until 2040. The estimated results can then be compared to historical data in order to validate the models behavior and accuracy. The BAU scenario can also be compared with the GEI scenario in the future. This allows green economy investments to be evaluated against current practices and can also be presented graphically.

Figure 2 illustrates the results that were obtained for the Western Cape's population. The population grows from 4.5 million in 2001 to 7.8 million in 2040. When the estimated population is compared with historical data, it is noted that the estimated graph follows the historical data within an acceptable level. The average life expectancy also increases from 53 years (in 2001) to 67 years (in 2040). With regards to education, total school students increases which is expected since the total population also increases over the same time period. The relative adult literacy rate increased and decreased back to 1 over the course of the simulation. This might be due to the population size increasing too fast for the education system as time progresses. This might also be due a lack of government investment to increases capacity for new students as population increases.

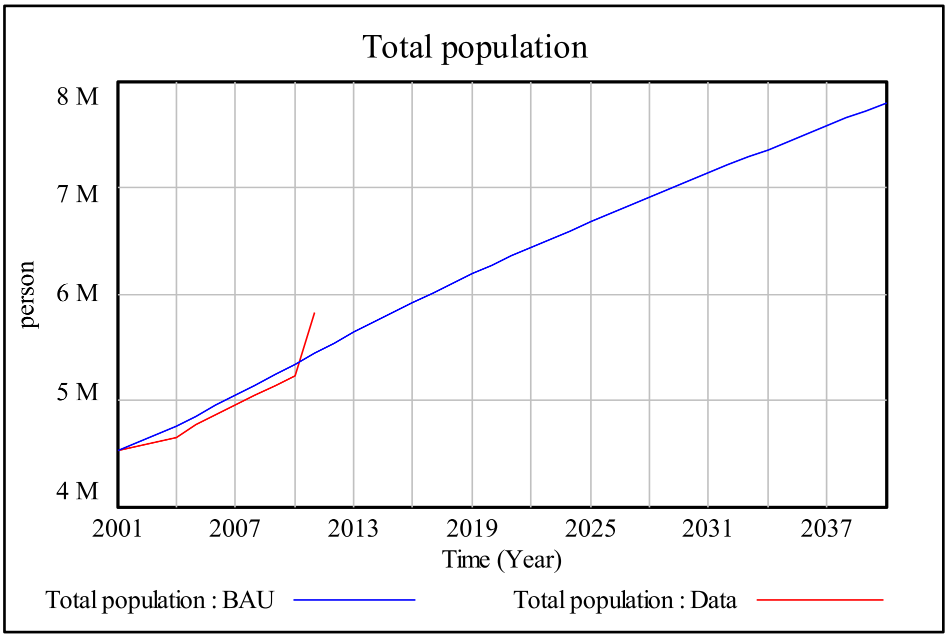


Figure 2: Population for BAU

The GDP per capita increases from R41 640.00 to R65 670.00 per person over the simulation period. The GDP for the Western Cape also increases over this period. The GDP growth is illustrated in Figure 3. It follows historical data accurately and fluctuate around 1.85% growth from 2019 onwards.

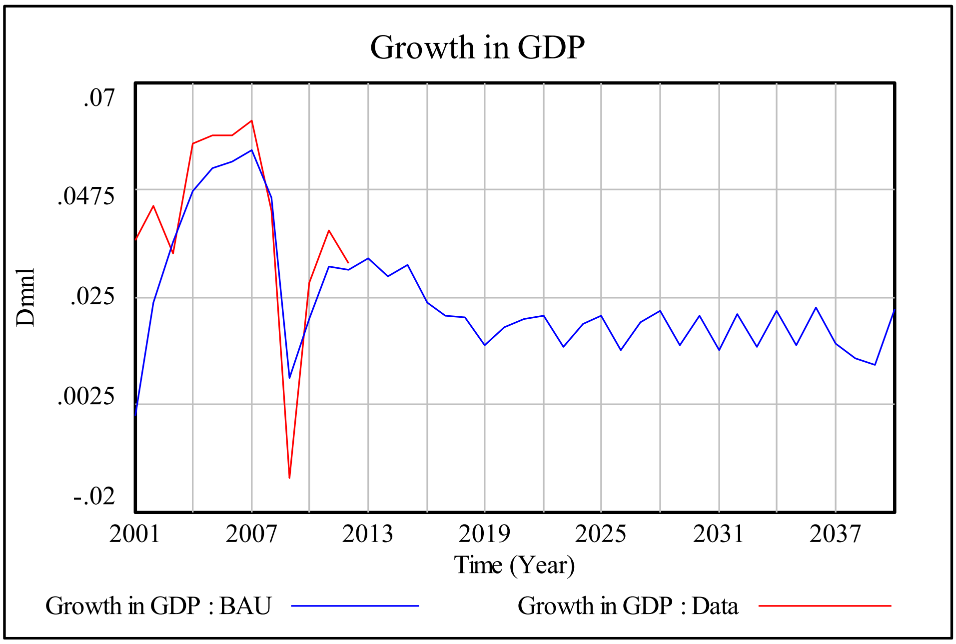
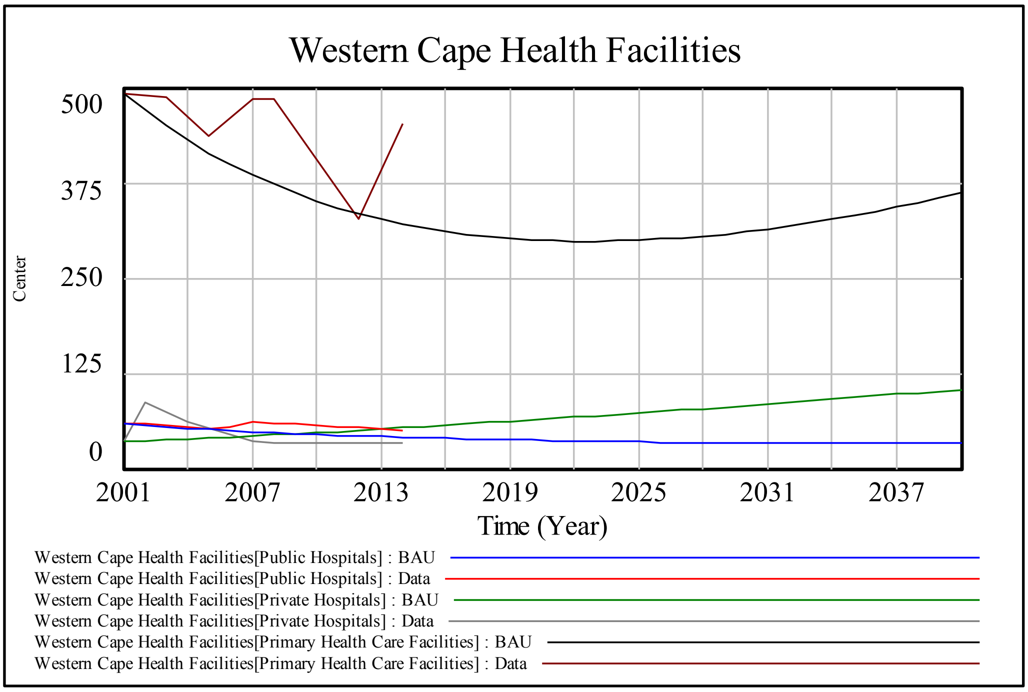
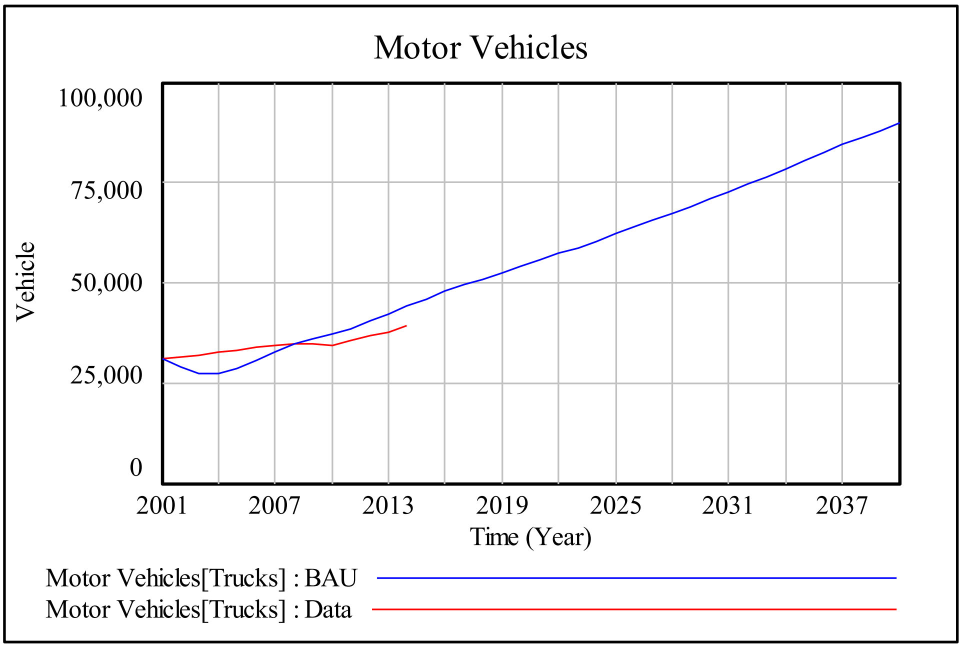


Figure 3: GDP growth for BAU

The results for the healthcare sector shows that the public health infrastructure (public hospitals, clinics, etc.) is decreasing over time. This is mostly due to the lack of government expenditure in the public healthcare sector. The private sector however shows an increase in private hospitals, which relates back to the increase in GDP and GDP per capita.



With regards to transport, road freight haulage increases sharply form 32.66 billion (in 2001) to 95.87 billion (in 2040) ton-km per year. This is a result of rail freight only growing by a slow rate over the same period, so more goods need to be transported by road for the growing population. The total kilometres of functioning roads decease due to an increase in road freight haulage (as noted above) and due to more passenger vehicles being on roads (due to increased population). The road freight haulage is linked to the number of live trucks on the roads that are recorded annually, the dynamics for the live truck population occur within the Live Vehicles sub-model and show an accurate correlation to historical data.



Water stress in the Province increases, which is a result of water sources remaining constant whilst the population increases. This creates a scenario of low supply and high demand of water in the province. Electricity demand for the Western Cape is met by local electricity supply throughout the duration of the simulated period. It should be noted that the supply/demand ratio decreases over time.

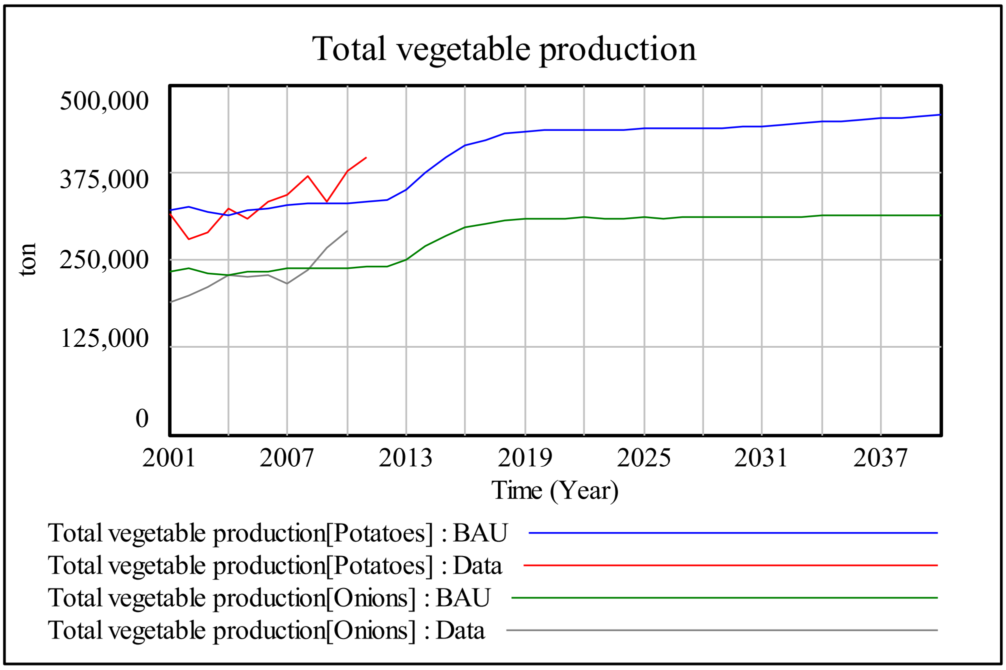


Figure 4: Vegetable production for BAU

Settlement land increases as population size increase, which is as expected. Agricultural land requirements however decrease for the food crops considered the simulation. This is result of an increase in yield per hectare over time due to more capital being invested into the agricultural sector. This increased capital investment also result in less labor employment in the agricultural sector. Food crop production is however not significantly affected and local and international demand is always met. Figure 4 illustrates the vegetable production form the BAU scenario as compared to historical data.

6 Conclusion

Globally, transitioning to a green economy is gaining relevance in both policy and academic domains. At the policy domain, green economy presents opportunity to not only the national government, but also to provincial and local governments. The Western Cape Province of South Africa identified smart living and working, smart mobility, smart ecosystem, smart agri-production and smart enterprise as the five key drivers for transitioning to green economy. In order to support and inform the implementation of these identified drivers, this paper developed a Western Cape Green Economy Model (WeCaGEM) to investigate the implications of green economy transition in the Western Cape Province of South Africa.

The model consists of 23 sub-models, with specific focus on Western Cape green economy efforts in water conservation, sustainable agriculture, sustainable and efficient transport infrastructure, renewable energies, energy production, CO_2 emissions, and sustainable public services. Preliminary business as usual scenario was executed with the aim of validating the simulated results with the historical data for some specific variables. Further validation with the experts will be undertaken, and plausible or planned scenarios will be established in order to analyze the green economy investment scenarios.

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