South African Green Economy Model (SAGEM)

Abstract

Green economy is a concept that covers several issues of sustainability. It is an economic paradigm that prioritises increasing the well-being and equitable distribution of economic benefits, while at the same time reducing environmental impacts. This paper introduces South African Green Economy Model (SAGEM) that was developed to test the effects of investing in green economy for selected sectors based on system dynamics approach. While the model consists of 14 sectors and 31 modules, emphasis for green economy was on four key sectors namely: natural resource management, agriculture, transport and energy. The baseline simulation (2011 – 2030) and historical trends for specific variables over the period 2001 to 2010 is also presented.

Keywords: *Green Economy, Sustainability, System dynamics, South Africa*

1 Introduction

In recent years, there have been calls for new sustainable development pathways. This is due to multiple and interrelated economic and environmental crises facing both developed and developing countries. Several challenges derailing sustainable path include: energy crisis; food crisis; water scarcity; biodiversity and ecosystem loss; climate security; desertification (Gouvea et al., 2012). Green economy is gaining interest because it is considered to provide potential to address these concerns (Cai et al., 2011; Xiaowei et al., 2011; Gouvea et al., 2012).

Despite these interests, there are still limited studies within the scientific domain (peer reviewed articles / studies) that models issues relating to green economy. Some these studies include Gouvea et al.,(2012), who utilises green quadruple helix framework to evaluate how water-intensive nations can develop additional competitive advantages in a green economy. Carfi and Schiliro (2012) utilises a competitive model for green economy to address climate change policy and creation of low-carbon technologies. Cai et al., (2011) utilises analytical and input–output models to investigate the relationship between the green economy and green jobs. These approaches however do not account for the cross-sectoral and dynamic nature of green economy concept. Incorporating the green economy concept into a formal model requires the use of mathematical model that integrates economic and physical dimensions of the social, economic and environmental systems being analysed (Musango et al., 2012; Department of Environmental Affairs (DEA). and United Nations Environmental Programme (UNEP). 2013)

United Nations Environmental Programme (2011) utilised system dynamics to evaluate the global green economy and accounts for the dynamic nature of the concept. System dynamics uses stocks and flows to represent the system being investigated and is well suited to jointly represent the economic, social, and environmental aspects of the development process. The approach was developed at the Massachusetts Institute of Technology and has greatly evolved over the last 60 years (see Forrester 1961; and Forrester 2007 for early and current examples on the use of this methodology). In system dynamics models, causal relationships are analysed, verified and formalised into models of differential equations (Barlas, 1996; Sterman, 2000), and their behaviour is simulated. The approach is useful to analyse a variety of development issues (Saeed, 1992; Saeed, 1998), including national policy analysis (Pedercini and Barney, 2010).

While United Nations Environmental Programme (2011) provides a useful analysis, one major criticism for the study is the lack of differentiation in relation to social equity and economic context (Victor and Jackson, 2012). Thus, using the same approach as United Nations Environmental Programme (2011), this paper presents a green economy model developed for South Africa (here in referred to as South African Green Economy Model (SAGEM). The purpose of the model was examine the question of whether equal or higher growth could be attained with a more sustainable, equitable and resilient economy in which natural resources would be preserved through more efficient use. The hypothesis was that, correct management of natural resources does not necessarily imply accepting lower economic growth going forward.

The development of the model was made possible through a partnership between the Department of Environmental Affairs in South Africa and UNEP. Within this context, the model was developed to explore the green economy transition for South Africa, with special attention given to the ability to meet low carbon growth, resource efficiency, and pro-job development targets.

2 The model (SAGEM)

The modelling process began with a workshop which was held late 2011 to conceptualize and identify the needs for the green economy modelling for South Africa. During this meeting, eight sectors were identified to have the potential to contribute to the green economy in South Africa. These are: energy; agriculture; manufacturing; recycling (waste and management); tourism; transport; water; ecosystem services (natural resource management).

In order to refine the sectors for the modelling, a Technical Stakeholder meeting was held in February 2012. The primary objective of the workshop was to prioritize: (i) the sectors that were to be focused; (ii) the targets to be aimed for; (iii) scenarios to be considered in the modelling effort.

Due to time and data availability constraints, the model was to focus on four sectors in analyzing green economy investment. The four main sectors that were selected include: natural resource management; agriculture; transport and energy. The details for targets and scenarios are found elsewhere (Musango et al., 2012; Department of Environmental Affairs (DEA). and United Nations Environmental Programme (UNEP). 2013)

SAGEM utilised system dynamics approach following the T21 framework, which is a planning tool that integrates the economic, social, and environmental dimensions of a country into a single, comprehensive, transparent, user-friendly analytical framework. The model was developed in Vensim software platform. In a broad sense, SAGEM was divided into fourteen sectors (see Table 1) and 31 modules (see Appendix 1). A description of each of the sectors, and their respective modules for SAGEM are discussed below.

Table 1: Green economy spheres and sectors

Environment	Society	Economy
Natural resource management	Population	Production
Land	Education	Investment and households
Water	Health	Government
Energy	Employment	
Emissions	Public infrastructure	
Minerals		

2.1 Environment sphere

The environmental sphere of the SAGEM consists of 6 sectors and 18 modules (see Table 1 and Appendix 1) which are discussed below.

2.1.1 Natural resource management

The natural resource management represents the environmental and biodiversity protection programmes, with a specific focus on the Working for Water programme. The sector is classified into two modules. The first one calculates the water quantity provision with the working for water programme, and consists of three stocks namely: accumulated restored land (ARL); cost of clearing invasive alien species (C_{iap}); and operating cost of maintaining restored land (OC_{iap}). The accumulated restored land is represented as:

$$ARL(t) = ARL(0) + \int [r_{RT}]dt$$

Where, r_{RT} is the restoration rate.

The second module estimates the potential electricity generation from invasive species. While the primary objective of Working for Water is reducing the area of land under invasive alien species, it has plans for value add activities. This is particular, generating electricity from invasive alien species biomass. This is the key value add activity that was investigated in this module, and it consists of one stock, namely, biomass plant capacity (BPC). This is mathematically represented as:

$$BPC(t) = BPC(0) + \int [r_{BCC} - r_{BCD}]dt$$

Where, r_{BCC} and r_{BCD} are biomass capacity construction rate and biomass capacity depreciation respectively.

2.1.2 Land

This module represents the land use in South Africa and includes forest land (FL), crop land (CL), agricultural land (AL), conservation land (CoL), invasive alien species land (IAL) and other land (OL). The invasive alien species is converted to other land and is represented as:

$$IAL(t) = IAP(0) + \int [r_{sol} - r_{rol}]dt$$

Where, r_{sol} and r_{rol} are rate of spread from other land and rate of restoration to other land respectively.

Other land (OL) can be converted to the different competing uses, and it is represented as:

$$OL(t) = OL(0) + \int \left[\sum (r_{rol}, r_{lol}, r_{clol}) - \sum (r_{sol}, r_{ols}, r_{oll}, r_{olc}, r_{olf}, r_{olcl})\right]dt$$

where: r_{ols} is the rate of conversion from other land to settlement land; r_{lol} is the rate of conversion from livestock land to other land (in ha/year); r_{oll} is the rate of conversion from other land to livestock; r_{olc} is the rate of conversion from other land to conservation land;

r_{lof} is the conversion rate from other land to forest land; r_{olcl} is the conversion rate form other land to crop land; and r_{clol} is the conversion rate from crop land to other land.

Although the land uses changes for the different land types the total land size in the country is (obviously) maintained.

2.1.3 Water

The water sector consists of two modules: the water supply and water demand. The water supply represents the yearly total water supply from renewable resources $(TRWR)$ and it is utilised to estimate the water stress index (WSI), which influences the production sectors. Total water demand from production sectors and domestic and municipal demand (TWD) for water are also estimated in this module. For the case of water demand, specific attention is given to the water demand requirement for the electricity generation sectors including: coal, wind, solar, nuclear and biomass. The water stress index is therefore represented as:

$$WSI = \left(\frac{TWD}{TRWR} \right)$$

2.1.4 Energy

The energy sector is categorised into energy production and energy demand. Energy production consists of electricity supply, which is further categorised into coal, nuclear, wind, pumped storage, hydro and solar; electricity technology generation share; and electricity prices. The electricity supply from coal represents the capacity of coal electricity plant, the amount generated given the capacity factor, and the potential for coal capacity reduction given energy efficiency measures. It was assumed that the required electricity generation from coal is the difference between the total electricity demand and the total electricity generation from other electricity technologies. The coal electricity generation module consists of two stocks, namely, coal energy capacity (CEC) and potential cumulative coal capacity reduction $(PCCR)$. These are represented as:

$$CEC(t) = CEC(0) + \int [r_{cec} - r_{dcc}]dt$$

$$PCCR(t) = PCCR(0) + \int [r_{pedr}]dt$$

Where, r_{cec} is the coal plant construction rate; r_{dcc} is the rate of coal capacity depreciation; r_{pedr} is the rate of potential electricity demand reduction.

In a similar manner, other electricity supply modules, mainly hydro, nuclear, pumped storage, solar and wind, represents the electricity generation from electricity technologies other than coal. To illustrate with wind module, this consist of three stocks namely, wind plant under construction (WPC), wind capacity (WC) and decommissioned wind capacity (DWC). These are represented as:

$$WPC(t) = WPC(0) + \int [r_{wpc} - r_{wc}]dt$$

$$WC(t) = WC(0) + \int [r_{wc} - r_{dwc}]dt$$

$$DC(t) = DC(0) + \int [r_{dwc}]dt$$

Where, r_{wpc} is the rate of wind plant construction; r_{wc} is the rate of wind capacity completion; r_{dwc} is the rate of decommissioning the wind capacity.

Electricity production is influenced by investments (installed capital capacity). The electricity production is computed taking into account the demand and production capacities. Demand is calculated by the sum of retail sales and distribution, distribution and transmission losses, and the electricity net exports, which results in gross electricity demand. Subtracting the gross electricity demand from the electricity generation from renewables, nuclear, hydro and pumped storage yields the coal electricity demand for electricity production.

The technology share module estimates the proportion in which each electricity generation technology contributes to the total electricity supply. In the case of electricity prices, this module describes the electricity prices, which are taken as exogenous. This assumption is reasonable for South Africa because the electricity prices are regulated by the National Energy Regulator South Africa (NERSA). The electricity prices are projected exogenously based on assumptions for NERSA's determination on different electricity growth after 2013. These are considered as: (i) BAU – 10%; (ii) average growth – 5%; and (iii) slow growth – 2.5%. Relative electricity prices have a major influence on production sectors, which in turn influence GDP and investments.

Energy demand on the other hand consists of electricity demand, oil demand and gas demand. These modules represent the drivers of energy demand in the medium- and long-term. The electricity demand estimates the future electricity dynamics by the different electricity users, and is driven by GDP, population and electricity prices. Oil demand is influenced by an exogenously determined oil price since South Africa imports approximately 64% of its oil consumption requirements. Gas production and consumption still plays an insignificant role in the South African energy market. The gas demand module is therefore assumed to be influence only by the GDP. It should be noted that the energy sub-model is estimated using a variety of endogenous inputs (e.g. GDP and population) and exogenous inputs (e.g. the case of electricity price).

2.1.5 Emissions

This consists of the air emission module which estimates the CO_2 emissions from the different sectors. These sectors include industry, categorised as electricity and non-electricity industry, which include: transport, agriculture, residential and services CO_2 emissions. The annual CO_2 emission is endogenously determined in the model. The module consists of one stock, cumulative air emissions (CAE). This is increased by the rate of annual CO_2 emissions (r_{ae}) and decreased by decomposition of air emissions (r_{dae}). This is mathematically represented as:

$$CAE(t) = CAE(0) + \int [r_{ae} - r_{dae}]dt$$

2.1.6 Minerals

This module represents the main mining activities, mainly coal, gold and PGM, and tracks the mineral reserves, both unproven and proven reserves. The resources side of each of these activities consists of two stocks, namely, undiscovered reserves and proven reserves. As an illustration, gold proven reserves (GPR) are increased by the rate of gold discovery (r_{gd}) and decreased by the rate of gold extraction (r_{ge}). On the other hand, undiscovered reserves (UGR) are decreased by the rate of discovery. These are represented as follows:

$$GPR(t) = GPR(0) + \int [r_{gd} - r_{ge}]dt$$

$$UGR(t) = UGR(0) - \int [r_{ge}]dt$$

In addition, the module calculates the corresponding energy demand and employment generated from these sectors.

2.2 Society sphere

The societal sphere of the SAGEM model consists of 5 sectors and 7 modules (see Table 1 and Appendix 1), which are discussed below.

2.2.1 Population

This represents the population of South Africa and was categorized according to sex (male and female) and age cohorts. The module consists of one stock, population (P), whose dynamics is depended on births (r_b), deaths (r_d) and net migration (r_{nm}). This is given as:

$$P(t) = P(0) + \int [r_b + r_{nm} - r_d]dt$$

The module is generally used to dynamically estimate the factors that influence populations (fertility rate and birth rate) and the way in which population influences environmental, social and economic indicators in other modules such as water demand, energy demand, and GDP.

As an illustration, a growing population results in an increase in the water demand, which in turn increases the total water demanded. With an increasing total demand, the water stress index also increases, implying a reduction in the water reserve margin relative to the demand.

A decreasing water stress index consequently negatively influences the production sectors (agriculture, industry and services), which in turn influences the size of GDP. The GDP, and in particular, per capita income, has an influence on the fertility rate and life expectancy, which in turn determines the level of population in the country (Figure 1). The main output of the sub-model is population, which was compared with the nationally available population data.

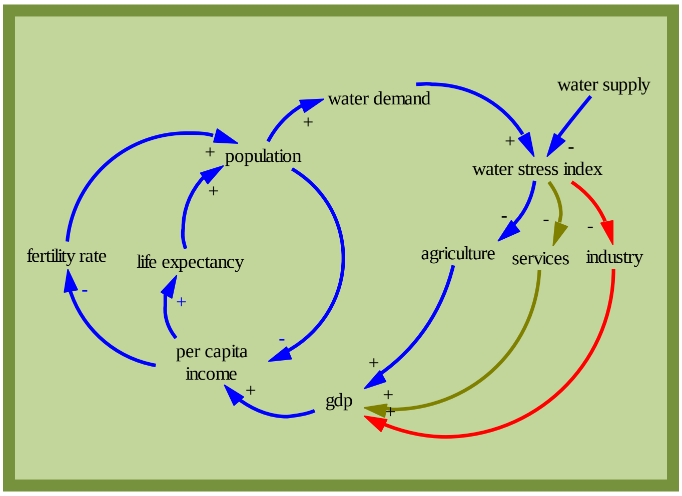

Figure 1: Causal loop of effect of population on water demand

2.2.2 Education

The module represents the advancement of the population through the education system, from the school going children (both primary and high school), to becoming a literate population. The module is categorised according to the South African education system of 7 years in primary school and 5 year in high school respectively. The government expenditure in education and per capital income is assumed as the main influences of entrance to school. The module consists of three stocks: students (S), who are increased by entrance rate (r_{er}) and decreased by completion rate (r_{cr}); young literate population (YLP), who increase due to completion of the education system; adult literate population (ALP), increased by the rate at which the young literate population become adults (r_{ba}).

These are represented as:

$$S(t) = S(0) + \int [r_{er} - r_{cr}] dt$$

$$YLR(t) = YLR(0) + \int [r_{cr} - r_{ba}]dt$$

$$ALR(t) = ALR(0) + \int [r_{ba}]dt$$

Generally, the module is utilised to estimate the access to education and the level of literacy rate. These in turn are utilised to estimate the broader socio-economic factors such as availability of labour, population and the GDP among others.

2.2.3 Health

This module aims to represent the access of basic health care based on the government expenditure on health. While access to health has influence on fertility and life expectancy, the sparse data for this sector did not allow for the model to be linked to other modules.

2.2.4 Public infrastructure (access to roads and transport)

This sector is categorised into roads infrastructure and transport. In the roads module, the process of road construction is estimated as influenced by government expenditure on transport and communication and the unit cost of roads construction. This is aimed at estimating the access to roads, which has an influence in the production sectors. The module consists of three stocks: roads under construction (RUC), which is increased by the rate road construction (r_{rc}) and decreased by completion of construction (r_{rcc}); functioning roads (FR), increased by roads completion (r_{rcc}) and decreased by disruption of roads (r_{rd}); and cost of maintaining roads, which is influenced by changes in cost of maintenance with an assumed exogenous cost growth. These are represented as:

$$RUC(t) = RUC(0) + \int [r_{rc} - r_{rcc}]dt$$

$$FR(t) = FR(0) + \int [r_{rcc} - r_{rd}]dt$$

The transport module on the other hand estimates the volume of roads, air and rail transport, which is categorised according to the goods and passenger transport. The travel volumes are calculated by multiplying the initial value of 2001 to the effects of GDP and population. The assumption is that, all other things being equal, the travel volumes increases as GDP and population increases. The associated emissions, employment and energy use from these transportation modes is also estimated. These are calculated based on the CO_2 emissions, employment and energy consumption factor for each of the transport modes, which are exogenously determined.

2.2.5 Employment

This represents the employment created in all the economic activities. The accumulation of capital in the main production sectors (agriculture, industry and services) is considered important in driving the growth in employment. The employment from production sectors consists of three stocks: agriculture employment (AE); usual industry employment (UIE); usual services employment (USE). These stocks are influenced by the rate of net agricultural hiring (r_{ah}), net industry hiring (r_{ih}); and net services hiring (r_{sh}) respectively, and are represented as:

$$AE(t) = AE(0) + \int [r_{ah}] dt$$

$$UIE(t) = UIE(0) + \int [r_{ih}] dt$$

$$USE(t) = USE(0) + \int [r_{sh}] dt$$

Estimation of employment from other sectors was disaggregated. These include: employment from restoration natural resource management, with specific focus on the Working for Water programme, employment from mining, transport and power sectors. The employment in all the sectors tends to adjust over time to the demand. Therefore, employment cannot be more than the supply of labour force.

2.3 Economy sphere

The economic sphere of the SAGEM consists of 3 sectors and 6 modules (see Table 1 and Appendix 1), which are discussed below.

2.3.1 Production (agriculture, services, and industry)

This represents the agriculture, services, and industry sectors that are utilised to calculate the gross domestic income.

The *agriculture* module module consists of one stock, the agriculture capital (AC), which is increased by rate of investment in agriculture (r_{ia}) and decreased by capital depreciation (r_{acd}). This is represented as:

$$AC(t) = AC(0) + \int [r_{ic} - r_{acd}]dt$$

The agriculture module also includes the crop production and differentiates between production utilising conventional and organic fertilizer. The agricultural production is based on the Cobb-Douglas production function, where land, labour and capital are the main factors of production, and are influenced by water availability, electricity prices, literacy rate and access to roads. Growth in the agriculture production is dependent in these factors of production.

Being a production sector, it does have an influence on macroeconomic indicators related to the green economy, as illustrated in Figure 2. An investment in ‘resource conservation’ and ‘agriculture capital’, will lead to an increase in ‘agricultural production’ with a consequent increase in GDP with opportunities for further investments.

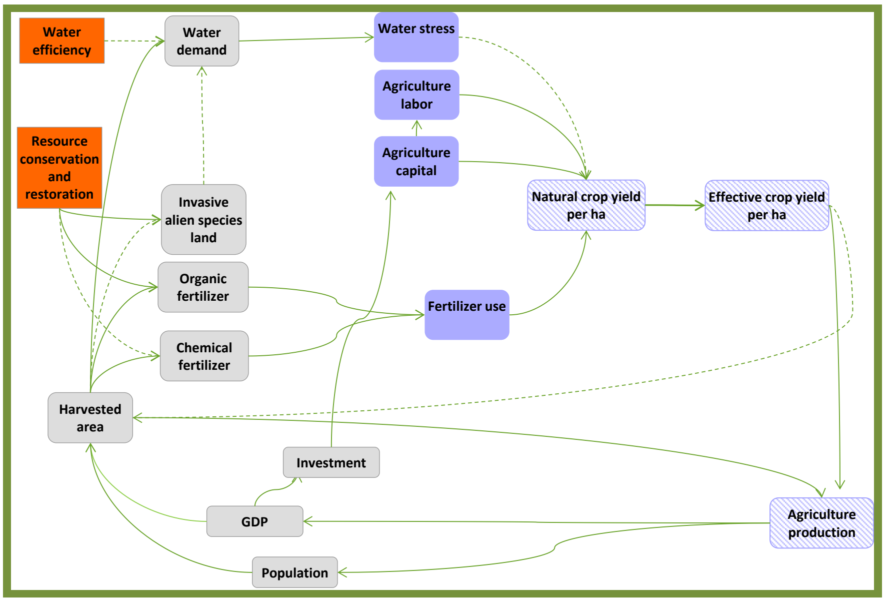

Figure 2: schematic representation of green economy effects of investment in agricultural production

These investments may be in 'health and education', which will increase the 'population' and 'labour force', which can then also boost 'agricultural production'; or it increases 'education levels' that will improve 'labour productivity', and also 'agricultural production'. Another option is to channel investments into 'pollution control', which can improve 'life expectancy' and associate benefits to the rest of the economy, or directly improve 'agricultural production'. Many other casual loops are possible, for this, and other sectors.

Similarly, the *industry and services* modules represent the industry and services production respectively, and employ Cobb-Douglas production function. Their production is also influenced by water availability, electricity prices, access to roads and the education level.

The *GDP* module shows the accounting relationships in the calculation of the major income-related indicators. These include the real GDP, which is influenced by the production sectors and the per capita income among others. GDP is one of the main outputs of the economic sector and the simulation results were similarly compared with the historically available data.

2.3.2 Investment and households

This represents the accounts of how the flows from the various economic production sectors determine the investment in the country and the household income. The investment arises from both private and public sectors, and is given as the sum of these investments from various sources. The investment is then allocated to the various production sectors.

On the other hand, the household income is divided into consumption and savings. The savings (PS) is a stock, which is increased by private savings (r_{ps}) and decreased by private investment (r_{pi}), and eventually becomes part of the investment. This is represented as:

$$PS(t) = PS(0) + \int [r_{ps} - r_{pi}] dt$$

2.3.3 Government

This module shows the various sources of government revenue including taxes, grants and interest, which are received both domestically and from abroad. The module also shows the government expenditure allocation to the various sectors.

2.3.4 Data collection

Based on the outcome of the workshop, the Sustainability Institute and Millennium Institute collected data in consultation with, and assistance from, the Department of Environmental Affairs, National Treasury, Department of Trade and Industry, and Development Bank of Southern Africa, among others. The data that were collected covered the various sectors and were obtained from various sources (see Table 2).

In utilizing the data, the approach was to first use nationally available data, or to use expert-based documents in South Africa. In cases where these forms of information were not available, the internationally best available data, such as the World Development Indicators and data of the International Energy Agency, were utilised. Where data were entirely unavailable, assumptions were made based on the experience of the Millennium Institute pertaining to the Green Economy Report (GER). The availability of data only allowed the simulation to start in 2001, and the modelling period was set to 2030.

Table 2: Data sources for the SAGEM modules

SAGEM Module	Data source
ENVIRONMENT	
NRM- water quantity provision with WfW	Various documents from SA experts on Working for Water Programme
NRM – potential electricity generation from invasive	Various documents from SA experts on Working for Water Programme
Land	STATS SA; World Bank Database (World Development Indicators); various documents on invasive alien land
Water (demand and supply)	Water stress index
Water requirements in electricity generation	DME / DoE Digest of Energy Statistics; Evans et al 2009
Electricity supply- coal	STATS SA; DME / DoE Digest of Energy Statistics
Electricity supply- nuclear	STATS SA; DME / DoE Digest of Energy Statistics
Electricity supply- hydro	STATS SA; DME / DoE Digest of Energy Statistics
Electricity supply- pumped storage	STATS SA; DME / DoE Digest of Energy Statistics
Renewable energy – solar	DME / DoE Digest of Energy Statistics; IRP 2010; SARi documents; Information on Engineering News
Renewable energy – wind	DME / DoE Digest of Energy Statistics; IRP 2010; SARi documents; Information on Engineering News
Electricity technology generation share	STATS SA; DME / DoE Digest of Energy Statistics; IRP 2010
Electricity prices	DME / DoE Digest of Energy Statistics; NERSA
Electricity demand	STATS SA; DME / DoE Digest of Energy Statistics; World Bank Database (World Development Indicators); International Energy Agency
Oil demand	DME / DoE Digest of Energy Statistics;
Gas demand	DME / DoE Digest of Energy Statistics;
Air emissions	International Energy Statistics; World Bank Database (World Development Indicators)
	STATS SA Minerals statistics; World Bank Database (World Development Indicators)
SOCIETY	
Population	STATS SA; World Bank Database (World Development Indicators)
Education	STATS SA; World Bank Database (World Development Indicators)
Health (access to basic health)	World Bank Database (World Development Indicators)

Roads (access to roads)	Various South Africa documents; World Bank Database (World Development Indicators)
Employment	STATS SA; World Bank Database (World Development Indicators); Green jobs report
Power employment	SARi documents; International Energy Agency
ECONOMY	
Agriculture	STATS SA; World Bank Database (World Development Indicators)
Industry	STATS SA; World Bank Database (World Development Indicators)
Service	STATS SA; World Bank Database (World Development Indicators)
GDP	STATS SA; World Bank Database (World Development Indicators)
Investment and Household	STATS SA; South African Reserve Bank
Government	STATS SA; South African Reserve Bank
Transport	DME / DoE Digest of Energy Statistics; World Bank Database (World Development Indicators)

3 Model validation

According to Sterman (2000) validation is a continuous process of testing and building confidence in the model. Models cannot be validated using a single test or ability to fit the historical data. Thus, it is not generally possible or plausible to classify the model as correct or incorrect (Sterman, 2000) but the model can be of good quality or poor quality (Barlas, 1996), suitable or not suitable. On a different note, Forrester (Forrester, 1961) argues that the validity of system dynamics model cannot be discussed without reference to a specific purpose. Thus, in order to make use of the standardized tests, it is always important to keep note of the environment in which the model is designed to operate and the questions it aims to answer. In short, validation enables one to: (i) understand whether the model is acceptable for its intended use 47; and (ii) build confidence in the model based on the inferences of the real system (Forrester, 1980; Barlas, 1996; Sterman, 2000).

Validation of SAGEM was an iterative process that ran throughout the modelling process. Various validation tests were utilised and included:

- direct structure validity test with the stakeholders and modelling team to ensure that the model was consistent with the knowledge of the south African green economy context;
- parameter confirmation tests in situations where data was not available in south African context in order to ensure it is consistent; and
- behaviour tests to determine how the model output is consistent with the historical data;
- qualitative validation using expert opinion during workshops in order to improve confidence in the usefulness of SAGEM.

4 Baseline simulation

The baseline simulation (BAU) of SAGEM is based on the assumption that the current trends will continue The simulation replicates the historical trend over the period 2001 to 2010 and assumes no fundamental changes in the policy or external conditions going forward to 2030. This simulation was set up and calibrated to reflect the baseline projections for the various existing sectoral models presented.

The real GDP is observed to grow over the simulation period (see Figure 3) due to the growth of the production sectors, namely: services, industry and agriculture. The result of the GDP simulation was compared with STATS SA data. For the past projections, the simulation results performs well compared with the STATS SA data, with an R-square of 94.8% and an average point-to-point standard deviation of 0.21%.

Between 2012 and 2030, the contribution for these production sectors to the GDP is expected to increase by 68%, 14% and 44% for the industry, agriculture and services respectively. Overall, this represents an increase in real GDP of 50.2% in 2030 relative to 2012.

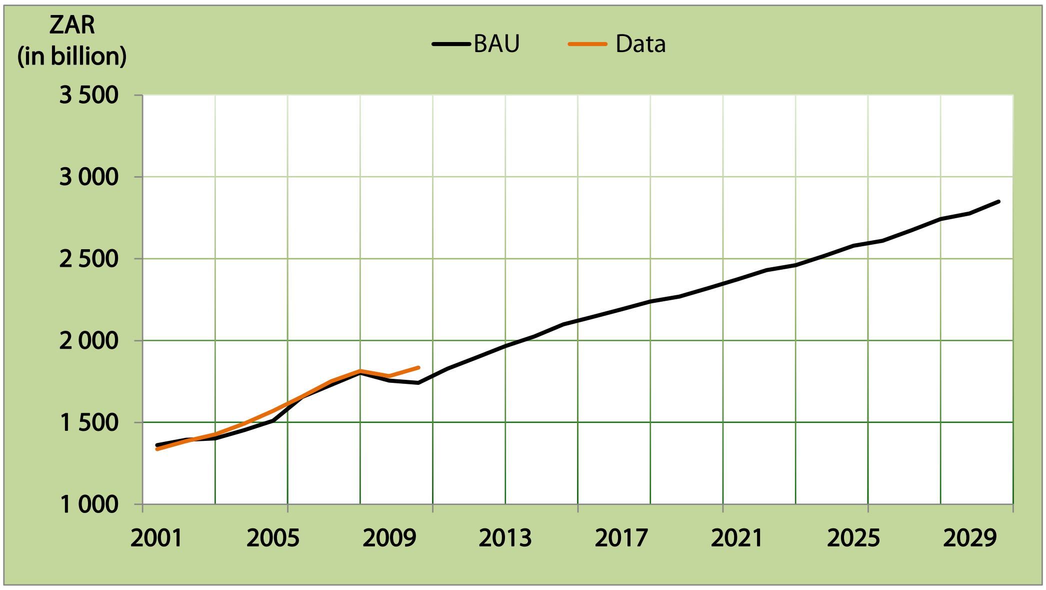

Figure 3: Comparison of real GDP in BAU with data

The growth in the production sectors also correspond to the employment opportunities that these sectors offer, with industry still providing much of the employment. The BAU shows a 24% and 36% increase in the persons employed in the services and industry sectors respectively. On the other hand, agriculture shows a drop in employment of about 14% in 2030 relative to 2012.

The total employment covers all the sectors. This was disaggregated for the industry sector, which also provides the employment in the mining and power sectors. Natural resource management is also contributing to employment, resulting from the business as usual allocation of some amount in the Working for Water programme. When considering the employment creation of the specific sectors, the transport sectors show an increase in employment by 2.3 times in 2030 relative to 2012 (see Figure 4).

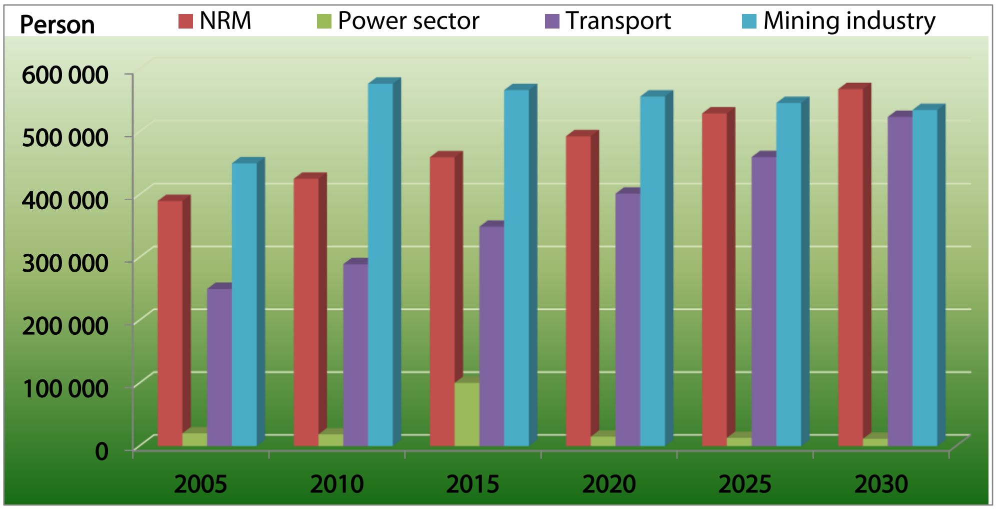

Figure 4: Key sectors employment in the BAU scenario

The population similarly grows from 51.7 million in 2012 to 61.4 million in 2030 (see Figure 5). The simulation from 2001 to 2010 matches the historical data from STATS SA, with an R-square of 97.9% and an average deviation of 0.09%. While the births are projected as declining, the life expectancy is increasing hence reducing the deaths.

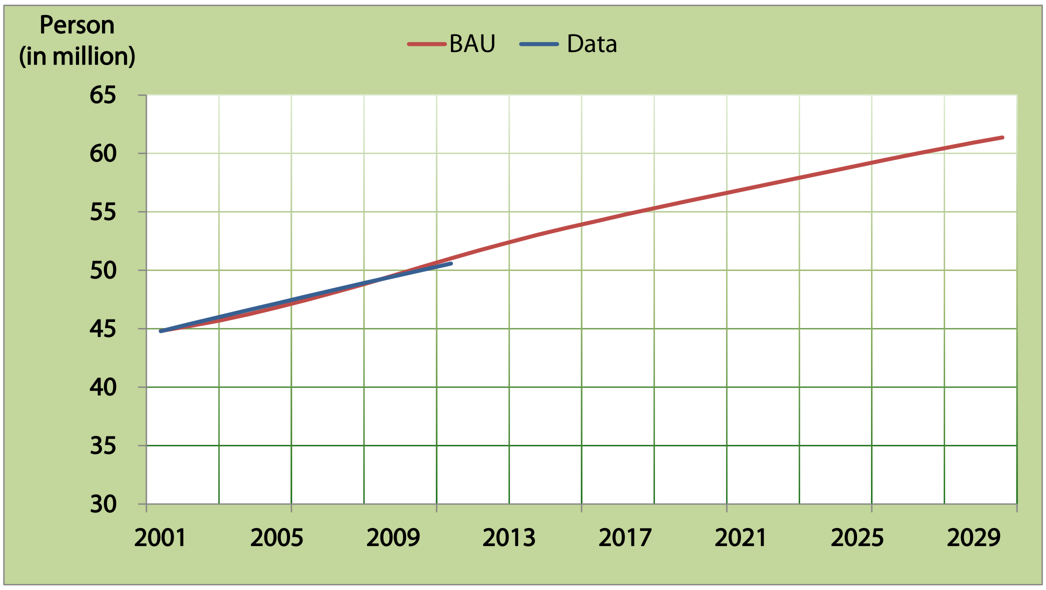

Figure 5: Comparison of population in BAU with data

Energy demand, that is electricity, oil and gas, are projected to grow, due to the growth in both population and GDP. In 2030, these are projected to reach 121643 thousand TJ, 112783 TJ and 232644 GWh for oil, gas and electricity demand respectively. In the case of electricity generation, the share of coal generated electricity remains relatively highly, though it declines from 91.7% in 2012 to 83.6% in 2030. This is due to the introduction of the renewable energy that is already committed in the BAU case. It should however be noted that the demand for electricity is unmet in some years of the BAU case.

In a similar manner, water demand is also projected to increase due to the growth in population and GDP. The demand reaches 13955 billion litres, representing 8% increase relative to 2012. With South Africa being a water stress country, receiving only an average of 500mm rainfall per annum, an increase in the water demand obviously increases the water stress index. To avoid compromising the already stressed water resources, water management practices would therefore be necessary.

In terms of land use changes (see Figure 6), the cropland increases to 16.5 million hectares by 2030, representing a 9% growth relative to 2012. This expansion, though marginal, is due to the increasing food demand from the growing population.

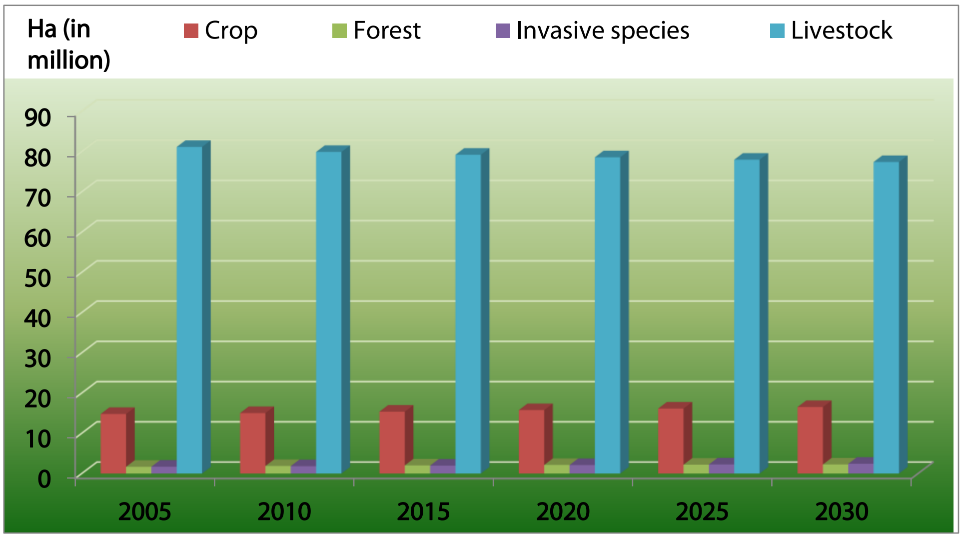

Figure 6: Selected land use changes in the BAU scenario

The area infested by the invasive alien species is observed to increase by 28% in 2030 relative to 2012. While the working for water programme is incorporated in the BAU, the rate of spread of invasive alien species is greater than the rate of restoration – hence the increase in the invasive alien species land. With similar programmes and targets in the BAU on the Working for Woodlands, the forestland is observed to increase by 0.9% per annum from 2012 to 2030. Similarly, settlement land also grows by 1% on average, reaching 2.14 million hectares. On the other hand, the growth in livestock land, and area infested by invasive alien species, decreases by 2% and 6% respectively.

The simulation result of the annual CO_2 emissions fits well with the World Development Indicators data, with an R-square of 80% and average deviation of 0.09% (see Figure 7). The annual CO_2 emissions are observed to be relatively increasing, reaching 475 billion kilograms by 2030. This is as a result of the increasing energy demand, population and GDP. The key sectors contributing to the increasing emissions are the energy, mainly due to power generation, and transport sectors (see Figure 8).

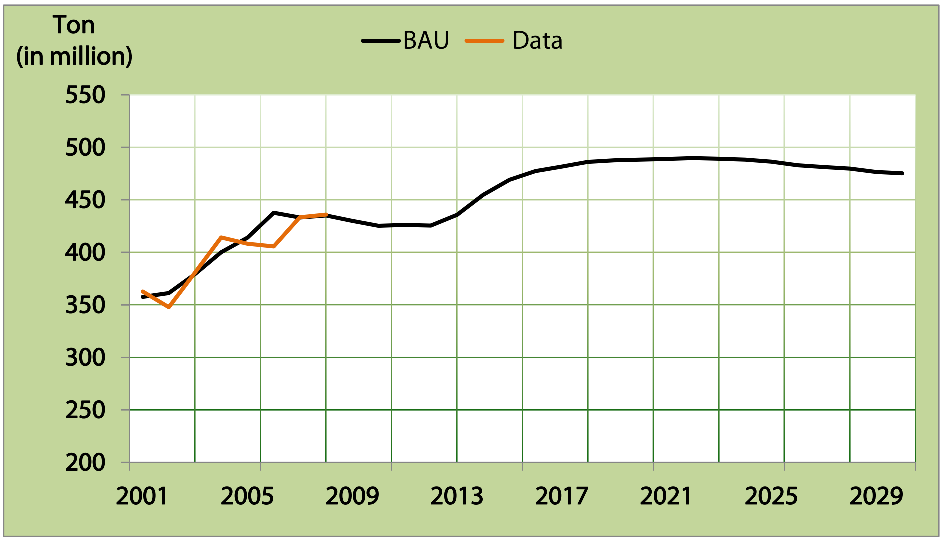

Figure 7: Comparison of CO_2 emissions in BAU with data

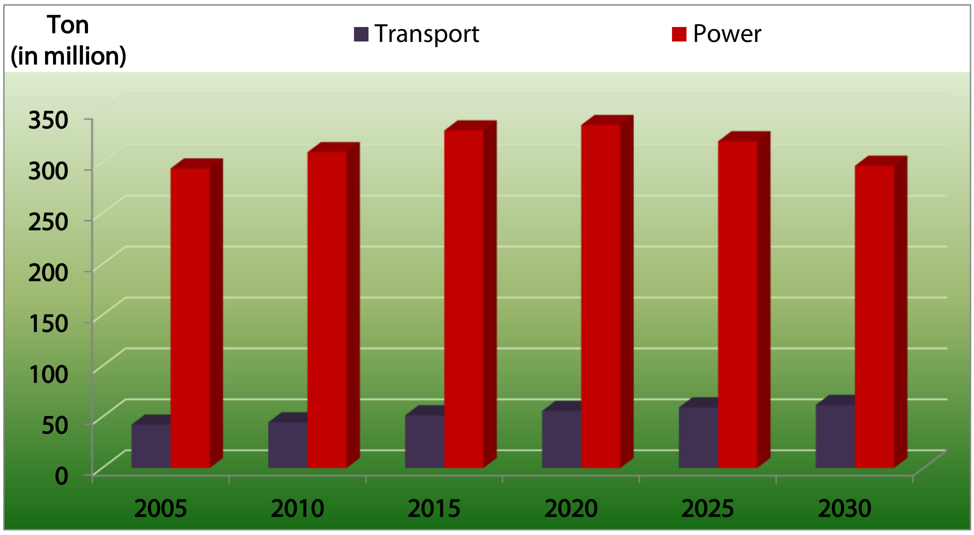

Figure 8: BAU CO_2 emissions in transport and power sectors

The power generation sector contribution to CO_2 emissions is projected to reach 297 million tons. Initially, the emissions from the power generation are increasing. This is due to the planned coal generation that was modelled in the BAU case. In addition, the renewable energy generation that is committed in the IRP2010 was modelled as part of the BAU scenario. This explains why the CO_2 emissions are growing at a decreasing rate. On the other hand, the transport sector emissions are increasing, with a growth rate of 1.6% per annum, between 2012 and 2030. The share of transport sector to CO_2 emissions is thus projected to rise from 11.1% in 2012 to 13% in 2030.

5 Conclusion

This paper introduced the South Africa Green Economy Model (SAGEM) that was intended to assess the impact of green economy investment of four key sectors. It was developed to evaluate the impact of green economy investment on medium- to long-term environmental, economic and social development issues. Given the data availability at a national scale, the time horizon for the model begins in 2001 and extends to 2030, which is in line with the current NDP time horizon. The simulation could also be easily extended further in the future if need be. The historical trends from 2001 to 2010 were utilised to ensure that the model replicates the characteristics of the behaviour of the issues investigated in SAGEM.

SAGEM does not capture all the inherent aspects that are necessary to allow for transitioning to green economy. For instance, the model only represents the national environmental, social and economic spheres without disaggregation at provincial or cities level. In addition, SAGEM only represents the environmental, social and economic spheres at a country level, without disaggregation at provincial or cities level. Additionally, SAGEM does not address the sources of funding for green economy and the different agents that may be responsible for transitioning towards green economy is not explicitly taken into account. Despite these limitations, the key contribution of SAGEM is its dynamic nature, cross-sectoral analysis and endogenous feedback loops within the various spheres, sectors and modules that are considered towards achieving green economy objectives (job-creation, low carbon transition and economic growth) in South Africa. The model has a potential to be extended to include other sectors that were initially highlighted as having a potential to contribute to green economy but were not modelled in detail. As an illustration, SAGEM is now currently being extended to include the manufacturing sector, in order to understand how the sub-sectors such as automobile, agro-processing and paper and pulp industry.

Appendix 1: All modules of SAGEM

Environment	Society	Economy
Natural resource Management sector 1. Water quantity provision with WfW 2. Potential electricity generation from invasive	***Population sector*** 19. Population	***Production sector*** 26. Agriculture 27. Industry 28. Services 29. GDP
Land sector 3. Land	***Education sector*** 20. Education	***Households and investment sector*** 30a) Household accounts 30b) Banks
Water sector 4. Water demand and supply 5. Water requirements in electricity generation	***Health sector*** 21. Access to basic health	***Government sector*** 31. Government accounts
Energy sector ***Energy production*** 6. Electricity supply – coal 7. Electricity supply – nuclear 8. Electricity supply – hydro 9. Electricity supply- pumped storage 10. Electricity supply – solar 11. Electricity supply – wind 12. Electricity technology generation share 13. Electricity prices ***Energy demand*** 14. Electricity demand 15. Oil demand 16. Gas demand	***Employment sector*** 22. Employment in different sectors - Industry employment - Agriculture employment - Services employment - Employment from NRM (invasive alien) 23. Power sector employment	
Emissions 17. Emissions from different sectors -Power sector emissions -Industry emissions -Transport emissions -Agriculture emissions	***Public infrastructure sector*** 24. Transport 25. Access to roads	
Minerals 18. Mining -Coal -Gold and uranium -PGM -Other		

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