

USING SYSTEM DYNAMICS TO EXPLORE GINI COEFFICIENT PARAMETRICS

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Thesis presented for the degree of

Masters of Science in Sustainable Energy Engineering

In the Faculty of Engineering & the Built Environment

Department of Mechanical Engineering

University of Cape Town

11 April 2014

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ABSTRACT

Modern economies are dependent on a reliable electricity supply for sustaining economic health and development, enabled by adequate energy planning and/or investment in capacity. Identifying drivers such as changes in income distribution that impact electricity demand is thus critical. This project made use of a system dynamics methodology with feedback loops to provide an insightful alternative to the conventional linear statistical empirical approaches such as multiple regression analysis and principal component analysis, generally used to explore the sensitivities of key driving forces which affect income distribution. The system dynamics simulation tool highlighted the direct causal influence of Gini coefficient on residential electricity consumption, by using equations as opposed to correlations. Results show that for a GDP growth rate of 2%, by year 2035, a Gini coefficient of 0.5 is linked to a 3.14% increase in residential electricity demand while a Gini coefficient of 0.4 means a 4.73% increase in residential electricity demand. This dynamic is an important consideration for energy planners since government has (and continues to) introduce policies and mechanisms to ensure a more equal income distribution and hence a decrease in Gini coefficient from 0.67 to lower values.

Keywords: System dynamics, income distribution, Gini coefficient, residential electricity consumption

DECLARATION

I Nalini Sooknanan Pillay do hereby declare that this Dissertation Report is original and has not been published and/or submitted for any other degree award to any other University before.

Signed by candidate

Signed..... Date: 10/04/2014

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APPROVAL

This Dissertation Report has been submitted for Examination with the approval of the following supervisors.

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DEDICATION

To my husband, Kiruben, for his overwhelming support and encouragement towards me to further my passion in engineering.

To my three children: Tejal, Anita & Nikhil for giving me unconditional love and support through the many hours spent away from them and on this project.

ACKNOWLEDGEMENTS

During this project, I experienced a pronounced learning curve in analysing system problems and in applying the system dynamics methodology to the topic of income distribution and residential electricity distribution. This project would not have been possible without the support of many people.

I would like to thank my university supervisor Dr Brett Cohen whose prompt responses, useful suggestions and painstaking dedication to detail, contributed towards a meticulous and comprehensive deliverable.

Eternal gratitude goes to Dr Willem Nel, my external supervisor, who spent endless hours in ensuring that every structure of the system dynamics simulator was robust, causally linked and rigorously tested. Extensive discussions enriched my understanding of macroeconomics, income distribution and electricity consumption dynamics.

Last but not least, my Eskom colleagues, for making this learning opportunity possible.

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LIST OF DEFINITIONS

Biophysical Parameters	These are real or objective e.g. paid work hours or electrical energy in kWh; as opposed to abstract units such as intensive variable indices e.g. energy intensity or GDP per capita.
Causal Loop Diagram	Explains the behaviour of a system by showing a collection of connected variables and feedback loops created by the connections
Causality	The relationship between variables where one variable is a direct consequence of another variable
End-of-pipe	Refers to solutions to treat the symptoms of a problem as opposed to the root causes
Endogenous	Used as an output of the model, calculated in the model
Equivalence Scales	Refers to assigning different weights to adults, dependents and children in a household to emphasize scale economies in a household.
Exogenous	Used as an output of the model, calculated in the model
Final Consumption Expenditure (Households)	All goods and services bought by households to meet their own everyday needs
Gini Coefficient	A measurement of the income distribution in a country where 0 is perfect equality and 1 is perfect inequality
Historical Reference Modes	Historic data and trends showing behaviour of a variable over time
Imputed Rent	Describes the benefit gained by the household compared with a similar household living in a rental dwelling with market rent
Principle of Accumulation	This states that all dynamic behaviour occurs when flows accumulate in stocks
Spaghetti Diagrams	These are also known as “physical process maps” or “point-to-point flow charts” or “work-flow” diagrams containing all conceivable parameters relevant to a system
Unintended Consequences	Occurs when an action gets taken and the effect that emanates was not anticipated

CHAPTER 1: OVERVIEW AND OBJECTIVES

1.1 RESEARCH OVERVIEW

Residential sector electricity consumption (largely for lighting and increased appliance usage) continues to grow directly proportionally to the rate of urbanization (Bensel & Remdio, 1994) and with increasing incomes (Tyler, 1994). When residential electricity consumption increases, energy planners are faced with a problem of ensuring that there is adequate capacity to meet the growing demand, especially during morning and afternoon peaks. Relatively expensive peaking power is then deployed when capacity is inadequate for load management (Meyers, Tyler, Geller, Sathaye, & Schipper, 1990). Ideally, implementing energy efficiency measures should assist in making up the energy demand gap, but in every country it remains challenging to rely on these demand side management strategies in instances of inadequate energy planning (Saboochi, 1999). To support improved planning and system optimisation, therefore, understanding the factors that may affect electricity demand is essential, one of which is income distribution – the main focus of this thesis.

Income distribution is a particularly important socio-economic policy issue if a society is in need of political stability and sustained economic growth (Camdessus, 1995; Voitchovsky, 2003). Demographics and changes in the labour force are linked to economic growth dynamics and income distribution. As demographics change and the number of people per age group changes, so too does the dependency of the unemployed and elderly on the employed population. Generally, an increase in the elderly population group has been linked to an increase in income inequality since an increase in the number of elderly people in a home means that (on average) a household's ability to earn income drops with a higher dependency burden and lower average income levels, (Chaiwat & Boonyamanond, 2011).

There are many studies which explore the relationship between income inequality and economic growth through statistical empirical research methods. Forbes (2000) reported a positive effect of income inequality on economic growth in developed and developing countries. Barro (2000) presents an alternative view and suggests that inequality encourages growth only in rich countries but there is an inverse relationship between inequality and economic growth in poor countries. Either way, empirical data indicates that there exists a linkage between income inequality and economic growth.

Economic growth, in turn, is linked to electricity consumption, with uni- or bidirectional causality being reported, depending on the researcher and the tools they use (Hossain & Saeki, 2012). A unidirectional causal relationship from electricity consumption to economic growth was proposed by Rosenberg (1998), linked to economic development and enhancing the quality of life. On the other hand, Ferguson (2000) suggested a unidirectional causal relationship from economic growth to electricity consumption. A bidirectional causal relationship is where economic growth and electricity consumption are jointly determined and have an impact at the same time (Glasure, 2002).

It is important to note that although these relationships are described in terms of causality, variables showing positive or negative correlations may not necessarily prove causality as explained by Gujarati (2004): "*Although regression analysis deals with the dependence of one variable on other variables, it does not imply causation...a statistical relationship in itself cannot logically imply causation. To ascribe to causality, one must appeal to a priori or theoretical considerations.*"

The measurement of the income distribution in a country can be done through various indices, including the Decile Ratio, the Robin Hood index, the Atkinson index, Theil's Entropy Measure, Kuznet's index and the most commonly used Gini coefficient and the Lorenz curve (Maio, 2007; Sloman, 2000).

The Gini coefficient is a measure between 0 and 1 where 0 indicates an equal distribution of income amongst all individuals and 1 implies that a single individual receives all the income (Benson, 1970). This can also be expressed in the form of an index that ranges between 0 and 100. The calculations and interrogation of the Gini coefficient dynamics is usually through statistical empirical analysis (Pinkovskiy, 2010; Andreev, Begun, & Shkolnikov, 2003; Voitchovsky, 2003). South Africa's Gini index, as reported by the World Bank in 2010, was 63.14 (excluding the impact of free services) (World Development Indicators 2010). The same source indicates that Lesotho and Botswana have very similar indices at 63.2 and 63 respectively. On the other hand, Mozambique is quoted a very favourable Gini index of 45.6.

Statistical empirical approaches, although effective, are limited due to the lack of feedback loops (Sterman, 1991). It is important to understand feedbacks so that energy planning policy makers can develop and maintain policies that contribute to an improvement in the economic welfare of the country.

To assist policy makers in energy planning, energy modeling tools are used which could involve either an optimization approach or a simulation and econometric approach or a synergistic combination of both (Sterman, 1991). Optimisation models are usually designed on constraints such as least cost while simulation models usually offer more flexibility by allowing multi-criteria decision analyses and scenario flexibility (for risk and sensitivity analysis) (Sterman, 1991). One type of simulation modelling is known as system dynamics, that allows the ability to incorporate feedback loops, time delays and non-linearity generally present in modelling the complexity surrounding energy issues (Longbin, 2007).

This study will involve the use of system dynamics (Sterman, 2000) as a decision support tool to provide a better understanding of the causality between residential electricity consumption, income inequality and economic growth to policy makers, energy planners and executive management for the purposes of strategic long-term electricity planning and load management.

Additionally, the study will link the economy with the demographic structure and social organization of society (Giampietro, Mayumi, & Sorman, 2012). An energy system within biophysical limits¹ will be modeled using a multi-level approach, in other words, within a sustainability context, by linking GDP growth to demographic structures and calculating GDP per paid work hour for the primary, secondary and tertiary energy sectors as opposed to the conventional measure of economic output (expressed as GDP per capita).

1.2 HYPOTHESIS

The effect of changes in income distribution on electricity demand have been largely neglected in the past. Inadequate long-term energy plans could result due to neglecting variation in income distribution over time because of the various causal relationships that exist between energy consumption and socioeconomics. It is proposed that a system dynamics model offers the potential to provide greater insights into the sensitivities associated with income distribution and residential electricity demand and provides a preferred alternative to conventional statistical empirical methods for energy planning.

¹ Biophysical parameters are real or objective e.g. paid work hours or electrical energy in kWh; as opposed to abstract units such as intensive variable indices e.g. energy intensity or GDP per capita.

1.3 RESEARCH OBJECTIVES

The development of two different models, each using a different dataset made up this study:

- The first model included Gini coefficient as an endogenous calculation (computed within the simulator) that changed as a function of changing income categories for a snapshot in time (based on the StatsSA 2005/6 data). This model will be referred to as the ***Static Model*** throughout the remaining report since it was used to establish a benchmark for influences for the second model through changing variable sensitivities for a static period of time. The key objective of the static model was to determine if there were any key influences between variables and if so, could insights be obtained in terms of qualitative judgement of the current methodology used for calculating Gini coefficient in South Africa and also if these were of such a significant nature that South Africa was being unfairly judged when rated on the international scale of Gini indices. The model was used for checking sensitivity analysis of certain variables but it has limitations in that equivalence scales were not used and actual quantitative results should not be relied upon.
- The second model used an exogenous Gini coefficient to endogenously calculate residential electricity consumption (based on data from 1994 until 2035 and included data for household incomes, population and GDP). This will be known as the ***Dynamic Model***.

The Static Model (SM):

The objective of this system dynamics model was to obtain an understanding of the sensitivity and influence of variables used in the calculation of the Gini coefficient on the results, by changing the variables that affected income distribution. The following was explored here:

- The contributions of various income categories (wages and salaries, capital, and imputed rent) and social grants (pensions from previous employment, annuities from own investment, old age pensions, disability grants, workmen's compensation funds, and family and other allowances) towards calculating an endogenous Gini coefficient.
- The sensitivity of Gini coefficient towards redistributive or free services such as electricity, water, and sanitation.

- Impact of changing average household size on Gini coefficient.

The Dynamic Model (DM):

The objective of this component of the study was to develop a system dynamics income distribution model that included feedback loops and time series information, as opposed to statistical empirical methods, to understand causality between income distribution, electricity consumption and economic growth. The model was developed using time series data of household income from 1994 until 2035. Empirical data was used from 1994 until 2011, while projected data using S-curves were made from 2012 until 2035. The DM was used for the following:

- To determine the impact of changes in the informal employment sector and the paid work sector on dependency ratios (old age dependency, child dependency, population on employed sector).
- To calculate and understand the difference between the conventional economic measures of GDP per capita versus a multi-scale integrated energy analysis of GDP per hour to evaluate the economy's level of productivity.
- To test the influence of changes in constant GDP growth rates in the primary energy sector (mining & quarrying, agriculture) and secondary energy sector (manufacturing and construction) on overall electricity demand; and compute the causally linked changes in employment, wages and electricity within these sectors. The employment in each economic sector was then used to calculate the dependency ratios.
- To establish what the mathematical and structural linkage of the Gini coefficient with residential electricity consumption is in order to better understand the requirement for electricity if income distribution patterns change.
- To observe the pattern in savings in households per decile as a function of changing income distribution.

1.4 REPORT OUTLINE

The current chapter provides a background discussion on income distribution dynamics and economic growth. It also explains the research objectives. The rest of the report has been divided into the following chapters:

Chapter Two: Literature Review and Methodology

The second chapter provides more context for the project through a detailed literature review of the history of system dynamics and its application to energy systems, as well as the factors that affect income distribution, and the factors that affect energy modelling. It also includes a description of the system dynamics methodology used in the study, including tools such as the model boundary chart and the causal loop diagram.

Chapter Three: Model Development & Structure

Chapter three explains the mathematical basis and equations used in the model development. It also presents the overall systems structure framing the integrated elements included in the model structure. Explanations are given on the stock-flow-feedback structures that have been developed using STELLA software, that were used to generate results.

Chapter Four: Results and Discussion

Chapter four presents and discusses the results obtained by running different scenarios from the base case.

Chapter Five: Conclusions and Recommendations

Chapter five concludes with a summary of the results and recommendations for building on the current scope and simulator structure for more in-depth analyses. The chapter also covers the limitations of the work done and how the insights gained can be used to allow policy makers and energy planners the ability to understand the income distribution linkage with social and economic policies.

A series of appendices provide the detailed results obtained from running the simulator.

CHAPTER 2: LITERATURE REVIEW AND METHODOLOGY

This Chapter provides an overview of the literature. It first discusses electricity demand and its relationship to economic development and income distribution so that the requirement for a causally linked model structure can be understood. It then looks at those key driving forces that affect income distribution, with a particular emphasis on demographics. This is followed by an explanation of how the Gini coefficient can be used as a measure to highlight income inequalities. Systems thinking and system dynamics is then explained as the research tools that will be used to look at the sensitivities of changing certain variables and observing the impact on income distribution. The methodology then follows the literature review and briefly outlines the research steps in the study. The last section explains the research instrument used.

2.1 OVERVIEW OF ELECTRICITY DEMAND, ECONOMIC DEVELOPMENT AND INCOME DISTRIBUTION

The functioning of a modern economy is critically dependent on electricity supply because of its role in infrastructure and economic development. (Masuduzzaman, 2012). In a perfect scenario, electricity supply and demand are in equilibrium; however, this is not always the case in developing countries (McCarthy, 2005), since shortages in capacity on the supply side may occur due to inadequate energy planning and/or inadequate investment in capacity for a rapidly advancing economy. South Africa's socioeconomic and political developments have induced a significant increase in electricity demand which has not been matched with adequate planning for the supply side (Creamer, 2010; MTRM Plan, 2010; Zietsman, 2012).

The increased use of electricity is closely related to increased urbanization and industrialization (Sadorsky, 2013), or as explained by Hall et al. (2003) "The history of human culture can be viewed as the progressive development of new energy sources and their associated conversion technologies." This energy source transition is also referred to as the energy ladder model, which explains how consumers migrate to more sophisticated energy carriers as their income increases, generally, the first migration is away from biomass fuels (e.g. wood) to transition fuels (e.g. coal) and then to electricity (Van der Kroon, Brouwer, & Pieter, 2013). Also, underlying the energy ladder transitions (other than for fuel efficiency) is society's need to demonstrate an improvement in socioeconomic status.

Urbanization affects the use of electricity since the movement of the population from rural areas to urban areas is associated with fuel switching from traditional biofuels to electricity and gas as there is an increased demand for services and for produced goods including electrical appliances and lighting. The increase in incomes for the urbanized allows for a higher standard of living accompanied by the use of luxury appliances (such as air conditioners) requiring electricity (Chow, 2001).

Industrialization is linked to increased energy use since more economically productive manufacturing uses more energy than conventional agriculture, measured empirically through industry value added as a percentage of GDP (Jones, 1991). Economic growth (through urbanization and industrialization) is considered to be a critical driver required to reduce the level of poverty by increasing the need for labour and wages within the economy (Bogdan Ion & Razvan-Dorin, 2012).

In a study of empirical data using an econometric methodology, Amusa et al. (2009) indicates that a 1% increase in income results in a 1.67% increase in the total demand for electricity in South Africa (essentially a price elasticity of demand). As early as 1975, through studies by Newman and Day (1975), it was found that income was a close proxy for household energy use and that the amount of household income linked to energy expenditure increased as income increased. However, depending on the income group, residential electricity consumption patterns may vary. Baxter (1998) explained that low income households do not require modern energy (electricity and gas) due to unaffordability of appliances and devices, whilst the higher income group expenditure on electricity remained high even with price increases (Khandker, Barnes, & Samad, 2012). The factors that affect income inequality and the related causality with residential electricity consumption are discussed in greater detail in the next section.

2.2 FACTORS AFFECTING INCOME INEQUALITY

There are many forces that drive economic inequality within communities and countries, with a certain degree of overlap between these. Garcia-Penalosa & Orgiazzi (2011) attribute these driving forces to:

- Changes in the demographic structure;
- Market incomes; and
- Changes in tax and redistributive policies.

Kaasa (2003) provides a more detailed list of driving forces together with an analysis of the relationship between these forces and income inequality using principal component analysis and multiple regression analysis (Table 1). These forces include:

NO.	CATEGORY	FACTORS
1.	Demographic factors	<ul style="list-style-type: none"> • Age structure of the population • Growth and density of the population • Urbanisation level of human capital • Level of education • Health of population
2.	Macroeconomic factors	<ul style="list-style-type: none"> • Inflation • Unemployment • Size of the governments expenditure • External debt • Foreign reserves • Changes in the exchange rate
3.	Political factors	<ul style="list-style-type: none"> • Privatisation, share of the private sector • Level of taxes • Trade openness • Freedom of labour movement • Social policy • Related economic policies
4.	Economic growth and the overall development of a country	<ul style="list-style-type: none"> • GDP growth • Technological progress • Structure of the economy

Table 1: Driving Forces that impact Income Distribution (Kaasa)

Kaasa's (2003) study concludes that demographic and macroeconomic development (over time), particularly with respect to increased participation in the labour market, results in reduced income inequality. The empirical calculations also indicate that the higher the intensive output of the economy in GDP per capita, the lower the income inequality.

The economically active population (EAP) is comprised of the employed and unemployed who are actively looking for work, age group between 15-65 years. In South Africa, the EAP in 2001 was 16.5 million and by 2011, this number increased to 17.7 million (Stats SA, 2012).

In the context of sustainability studies, societal demographics are essential to understanding the long-term implications for the economy.

South Africa has a small population in the <15 years old category (Figure 1) (approximately 28.4% of the total population in 2012) (Stats SA, 2012), infers far less contributions to the active labour market in a time span of 20 years. This movement in concentration of the population will result in short-term or long term effects depending on the time span being considered. Refer to Figure 1 for an illustration of the 2012 demographic profile or population pyramid.

Figure 1 shows a low population concentration at the 0-19 year age group which will ripple through the economy and after a 20 year window, will emerge as an increase in the aged population concentration.

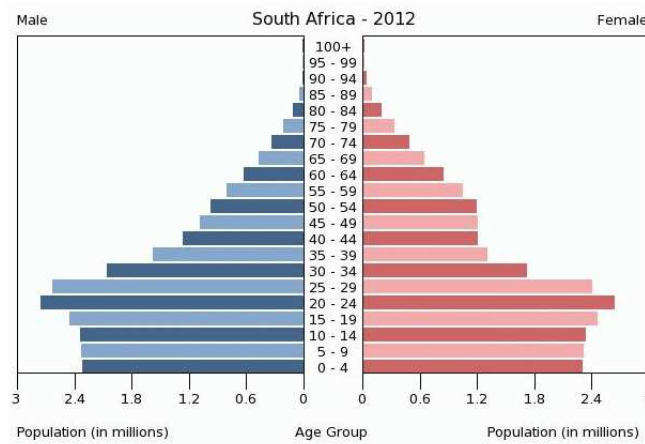
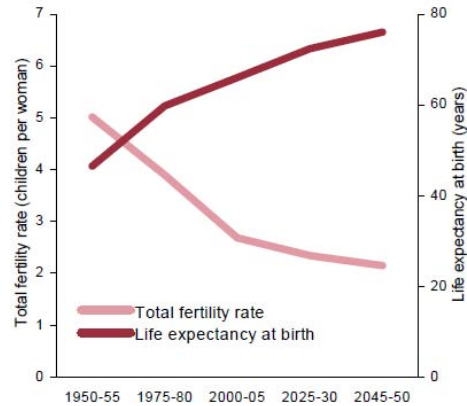


Figure 1: 2012 Population Pyramid for South Africa (CIA World Factbook, IndexMundi)

Thus the economy's ability to grow is subject to "lag-time" dynamics (Giampietro, Mayumi, & Sorman, 2012). These changes in demographics and the growth in population must be tempered by an increase in productivity measured by an active, employed labour market. In other words the rate and magnitude of production must offset the amended increase in consumption due to an increase in population. Lower fertility trends couple with increased life expectancy appears to be the growing world trends, but largely so for developed and developing countries, then resulting in an expectation of more adults and elderly and less children in relative terms (United Nations, 2002) – refer to Figure 2.



**Figure 2: Total fertility rate and life expectancy at birth: World trends from 1950-2050
(Population Division, DESA - United Nations)**

Brazil showed the most significant drop in fertility among developing countries over time (Simão, Horta, & Wajman, 2001) and in South Africa the fertility rate shifted from 2.91% in 2001 to 2.35% in 2011 (StatsSA, 2011).

Middle aged workers tend to have higher incomes than young workers due to higher experience levels. When the number of young workers increases, their average incomes drop further below the average incomes of the middle age groups, increasing income inequality; whilst an increase in the number of middle age workers implies a decrease in the average incomes and this average moves closer to the average incomes of the younger age groups. The effect is then a decrease in overall income inequality (Williamson & Higgins, 2003). The findings were based on an empirical model that was applied to inequality data compiled by Deininger and Squire (1996) to test the effects of demographic transition as well as technological and structural change on income inequality.

The age structure dynamics also impact many socioeconomic issues and policies. For instance, countries with a high percentage of under fifteens would more likely experience a higher demand for education as opposed to health services (which could potentially be displaced if the majority of the population was 65 and over). Social policies have to factor in social security plans for an increase in the aged (over 65 years) (Kim & Hong, 2008). More important than this, is that depending on the age structure, the average income per group will change and hence the overall income distribution patterns will also change. Demographic age structure dynamics also link up with the macroeconomic driving force, specifically, unemployment.

Empirical calculations indicate that unemployment is expected to increase inequality since unemployment benefits are much lower than wage benefits (gross income minus taxes) (Biewen & Juhasz, 2010). Regression analysis conducted on data received from 6 metropolitan areas in Brazil indicated that unemployment increased inequality while inflation aggravated the situation by moving the middle-income groups closer to poverty (Cardoso, Urani, & Paes de Barros, 1995). The middle income group moves closer to poverty since inflation means less disposable income and this group generally ends up selling their assets to smooth consumption with a small chance of earning it back at a later stage. Sen (1997) explains unemployment as preventing the full national output from being realized due to the lack of income from the population that could have been contributing to economic development. For example, South African statistics for 2011 indicates that although there were 17.7 million EAP, the total population that could have generated economic growth was actually 33.9 million i.e. the total South African population between 15-64 years old – a 48% under-utilization of the labour force (SAIRR, 2012).

Although originally not intended to be used for this purpose, GDP per capita became the conventional metric to reflect an economy's health and has been used when setting economic policy (Cha, 2013). The problem with using GDP per capita to reflect socio and economic conditions is that (like the Human Development Index), they are "*averages that conceal wide disparities in the overall population*" (Kelley, 1991).

Giampietro (2012) advocates an alternative approach to the conventional economic indicators so that the environment and society is linked to economic spheres and contextualized within a sustainability framework by making GDP an intensive measure of added value in Rand per paid work hour (generated by the paid work sector). This approach allows the demographic structure to be causally linked to the economy and society dynamics. This is achieved by calculating the flow of added value generated through paid work and expressing economic performance as GDP per hour of labour supply instead of relying on intensive variables such as GDP per capita. It then becomes apparent how the changes in age structure and related demographics impact the labour market.

As far as the measurement of income distribution is concerned, there are many explanatory indices and measures including the generalized entropy index, the Atkinson index (Atkinson, 1970), range ratios, the McLoone index, the coefficient of variation, Theil's index (Conceicao & Ferreira, 2000), income shares and income quantile ratios, the Hoover index and the Gini index (Hale, 2004; Charles-Coll, 2011). Other less known indices include the Bonferroni and the De Vergottini indices (Barcena & Imedio, 2008). The Gini index is the most commonly

used metric to explain income inequality, derived from the Lorenz curve framework (Maio, 2007).

2.3 MEASURING INCOME INEQUALITY USING THE GINI INDEX

The Lorenz curve (developed by Max O Lorenz in 1905) is one possible mathematical representation of income distribution, and plots the cumulative percentage of total income received against the cumulative number of individuals/households; starting with the poorest individual or household. This curve is suggested to give a characteristic representation of empirical data on these variables (Lorenz, 1905) (Gastwirth, 1971).

Italian Statistician Corrado Gini (1912) introduced the Gini index (also known as the Gini coefficient or Gini ratio) to highlight income inequalities. It measures the extent to which the distribution of income (or consumption) among individuals or households within a country deviates from a perfectly equal distribution (Farris, 2010) (Sun, 2007).

The Gini coefficient measures the area between the Lorenz curve and the hypothetical line of absolute equality, expressed as the percentage of the maximum area under the line, as shown in Figure 3 (Lubrano, 2010).

Applications for this index range from sociology, economics, health sciences (Illsey & Le Grand, 1987) and ecology to chemistry, agriculture and engineering.

Gini's Coefficient is mathematically expressed as follows for population with increasing income ordered so that for: 1, 2, 3... n, the income is $x_1, x_2, x_3... x_n$ with $x_1 < x_2 < x_3... < x_n$ (Tziafetas, 1989):

$$G = \frac{\sum_{i=1}^n (2i - n - 1)x_i}{n \sum_{i=1}^n x_i}$$

Where, G is the Gini coefficient

n = number of individuals (households) in a group

x_i = income (expenditure) of i^{th} individual (household)

In a perfectly equal society (represented by the straight line in Figure 3), 10% of the population will receive 10% of the income, 20% of the population will receive 20% of the income etc. In such a society the Gini coefficient is zero. The Gini coefficient can vary

between zero and the highest possible value of 1. When the Gini coefficient lies at 1, it means that 1% of the population receives 100% of the income (Benson, 1970).

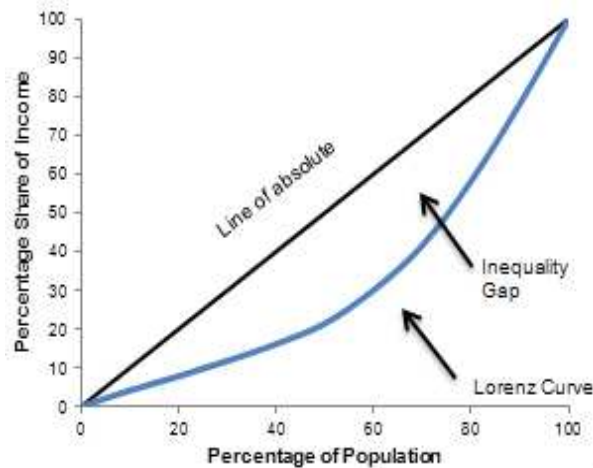


Figure 3: Schematic of the Lorenz Curve and Gini Index

In considering differences in Gini coefficient between countries (or even provinces), there are two major considerations to ensure a consistent comparison i.e.:

- The country's average income level (South Africa is considered a middle income, developing country - (McCarthy, 2005)), and
- The distribution of that income among the population (Kaasa, 2003).

If the country's average income level is higher than that of other countries, but its income inequality is also higher than the average level, then the poorest quintile of the population may appear to be in a worse displacement than the poorest quintile in some other country whose average income level is lower, but whose income inequality is lower, too e.g. the poorest 10% in the United Kingdom have more average income than the poorest 10% of Portugal (Bradshaw, 2009). Essentially, the distribution of income has to be considered alongside the level of income.

IHS Global Insight Southern Africa calculated the Gini coefficient at 0.68 in 2002 and 0.63 for 2011 (SAIRR, 2012). South Africa has one of the highest Gini coefficients in the world (Bosch, Rossouw, Claassens, & Du Plessis, 2010).

Figure 4 was plotted from work done by Bosch et al. (2010) and shows the impact of including factors such as taxation and social grants in the calculation of the Gini coefficient. If income from work, individuals, capital and imputed rent is included, the Gini coefficient is calculated at 0.70, however, this number drops to 0.65 when social grants are considered and drops to 0.61 when free services are added and drops even further when taxation impacts are considered, to a value of 0.59.

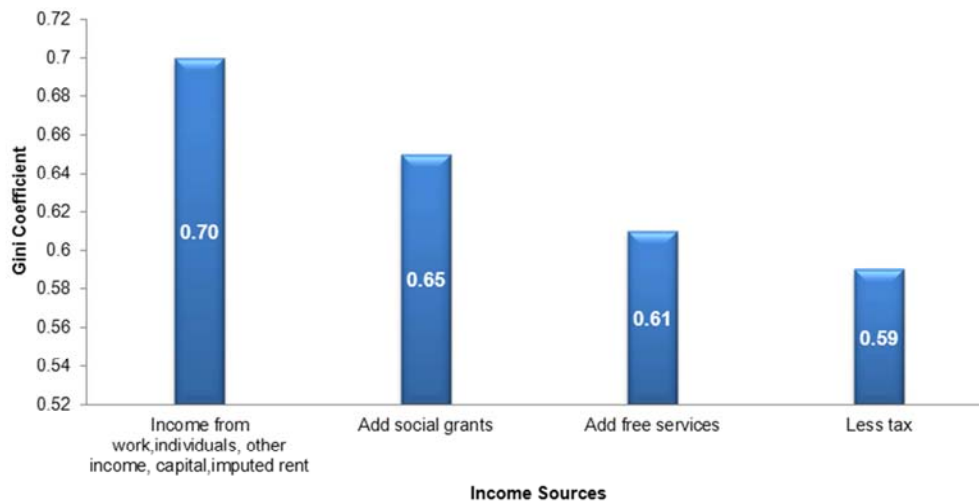


Figure 4: Gini Coefficient Based on the World Bank Definitions 2006 (Bosch)

Bosch et al. (2010) notes that calculations of the Gini coefficient by Stats SA is higher since it excludes the impact of free housing and free basic services to poor households. This is an important observation since these redistributive measures were specifically designed to impact government policies aimed at income redistribution. The study which follows will explore comparisons in computed Gini coefficients using Stats SA 2005/6 income/expenditure data (2008).

2.4 CURRENT TOOLS AND MODELS FOR UNDERSTANDING INCOME INEQUALITY

Many methods have been used to find the correlation between the factors affecting income inequality and the Gini coefficient; including multiple regression analysis and principal component analysis. Multiple regression analysis provides information on correlated variables but results in multi-collinearity (non-measurable factors) whilst principal component

analysis makes it possible to reduce the data sets by grouping a large number of similar variables together (Kaasa, 2003). Factor decomposition has also been used (Jenkins & Van Kerm, 2005).

These methods all allow for a linear statistical empirical approach to establishing the relationship between factors that affect income distribution. No literature was found that indicates that system dynamics simulators have been constructed to understand these linkages through a non-linear approach. System dynamics is a method that is based on systems thinking principles that is suggested to have application here.

The advantages of using system dynamics is:

- It offers a transparent parameterised causality structure which provides better understanding of the system variables.
- The causality structure allows explicit feedback so that changes in present value parameters, such as free basic electricity, feeds back as inputs to future behaviour while facilitating causal linkages to other system parameters such as electricity consumption.
- Allows sensitivity analysis to determine which variables influence the overall system in a significant manner and allows assessment of scenarios to support the understanding of the variables that affect income distribution.

2.5 SYSTEMS THINKING AND SYSTEM DYNAMICS

2.5.1 SYSTEMS THINKING

Austrian born biologist Ludwig von Bertalanffy advanced what he called “Allgemeine Systemlehre” or “General Theory of Systems” in the first half of the 20th Century, together with other seminal thinkers such as North Whitehead, Kenneth Boulding, Anatol Rapoport, Paul A. Weiss, Ralph Gerard, Kurt Lewin, Roy R. Grinker, William Gray and Nicolas Rizzo (Laszlo & Krippner, 1998). He introduced his hierarchical principles of organization in his paper “A quantitative theory of organic growth” in 1938. The Cybernetic Movement (which emerged from the general system theory work), was led by Norbert Wiener and John von Neumann, and formed after World War II and included a group of mathematicians, a neuroscientist and engineers (Umpleby & Dent, 1999). This group illustrated the concept of

system levels, wherein different interactions take place and result in non-linear behaviour. Systems theory was introduced to the bigger scientific community by Meadows, Forrester and Lovelock, and later evolved into an accepted and well-used discipline and methodology by many more system dynamicists. System dynamics emphasizes system structure and dynamic system behavior, modeled as feedback loops between stock and flow variables (Schwaninger, 2006).

Besides feedback loops that may result in unintended consequences², causality considerations between the variables within the system is essential. If there is no understanding of the interacting elements within a system, most solutions are derived from “end of pipe”³ approaches; where a focus is on alleviating the symptoms after an event has occurred, rather than finding and addressing the root cause of a problem (Haraldsson, 2000). This type of linear approach is also as a result of not being able to find leverage points due to a lack of systems thinking and the appropriate modeling approach.

Experts with years of experience and excellent judgement rely on a “*representation in memory of information with the same structure as that being modelled*”, also known as mental models (Johnson-Laird, 1999).

Unfortunately, these mental models do not have structured time delays or feedback loops built into them due to the limitation on the processing capacity of the human working memory (Johnson-Laird, 2010). These modeling shortfalls are satisfactorily addressed through simulations such as system dynamics which project the behaviour of a system based on varying possible alternative values of selected variables (Barnett, 2003).

A technical definition of system dynamics is provided by Dykes (2010) as “*a system of differential equations solved using numerical techniques at a sequence of time-steps with complex feedback relationships between system variables*”.

2.5.2 HISTORY OF SYSTEM DYNAMICS AND ITS APPLICATION TO ENERGY SYSTEMS

System dynamics has its origins in the mid 1950's when Professor Jay Wright Forrester (ex-Chair at the MIT's Sloan School) got involved in a project with the General Electric Corporation at the Kentucky plant where managers were confronted by oscillations with a three-year period in their component inventories and workforce numbers. The problem had

² Unintended consequences occur when an action gets taken and the effect that emanates was not anticipated

³ End-of-pipe solutions refer to treat the symptoms of a problem as opposed to the root causes

been attributed to business cycles and despite management's efforts, the oscillations could not be resolved. Forrester's interpretation of the situation was that the system had many feedback loops so through hand calculations and drawings, he confirmed that the effect of the internal policies being implemented were generating the opposite effect to the one intended and was in fact worsening the oscillations (Lane, 2007).

The initial stock-flow-feedback structures that he originally developed evolved further into a computerized version (SIMPLE: Simulation of Industrial Management Problems with Lots of Equations) with the help of Richard Bennet in 1958 (Forrester, 1995). Fox & Pugh subsequently refined the SIMPLE compiler in 1959, and this became known as DYNAMO (DYNamic MOdels) (Pugh & Richardson, 1981). The late 1950s and 1960s saw system dynamics largely being applied to managerial and corporate problems and the publication of the book "Industrial Dynamics" (Forrester, 1961).

In 1968, Professor Jay Forrester was invited by the Club of Rome to participate in a meeting in Bern, Switzerland. The Club of Rome is an organization dedicated to solving what was known as "*the predicament of mankind*" whereby concerns centred around demand being placed on the earth's carrying capacity by the world's exponentially increasing population. Forrester was asked if system dynamics could be used to model this problem and subsequently came up with the first socioeconomic system dynamics model known as the WORLD1 model. The WORLD1 model was later refined and evolved into WORLD2 which was accompanied by the book "World Dynamics" (Forrester, 1971a). Donella Meadows and her associates then expanded the scope of modelling to construct the WORLD3 model, together with a published book known as "The Limits to Growth" (Meadows, Meadows, Randers, & Behrens, 1972).

When John Collins, the former mayor of Boston, got a position as a visiting professor of urban affairs at MIT, collaboration between Collins and Forrester resulted in a book titled "Urban Dynamics" (Forrester, 1969). Besides being controversial in terms of reflections on urban policies, another important lesson learnt from this exercise included the fact that counter-intuitive policies yield (unexpected) successful results.

These initiatives encouraged further development in the field of system dynamics such as Roger Naill's natural gas model (COAL1), based on the life cycle theory of oil and gas discovery and production investigated by M. King Hubbert (Djotaroeno, 2010). Naill's work and other efforts took system dynamics into the energy modelling domain. Developments in system dynamics based energy modelling is illustrated in the "lineage" diagram (Figure 5).

The COAL1 model was part of the doctoral dissertation undertaken by Naill under the supervision of Dennis Meadows and was called COAL1 because his analysis showed that the best fuel for the U.S. economy to rely on was coal (Naill, 1976). Improvements to COAL1 contributed towards the development of the FOSSIL1 model, which looked at the transition of an economy as it moved from a fossil fuel driven scenario to one powered by alternative energy sources (Budzik & Naill, 1976). FOSSIL2 was improved and transitioned into the IDEAS model which was used by the United States as the National Energy Policy Model (Energy, 1993).

Naill and Hubbert's work was used as a basis for work done by John Sterman, Richardson and Davidsen in the 1970s, who used experimental data for forecasting the ultimately recoverable amount of oil in the world and in the United States (Sterman, Richardson, & Davidsen, 1987). The results of this study confirmed Hubbert's work that a life cycle approach is an accurate reflection of the ultimate recoverable resources, provided that the resource is at such a stage in the life cycle that the effect of depletion becomes the dominant factor and depresses the growth rate of accumulated resources.

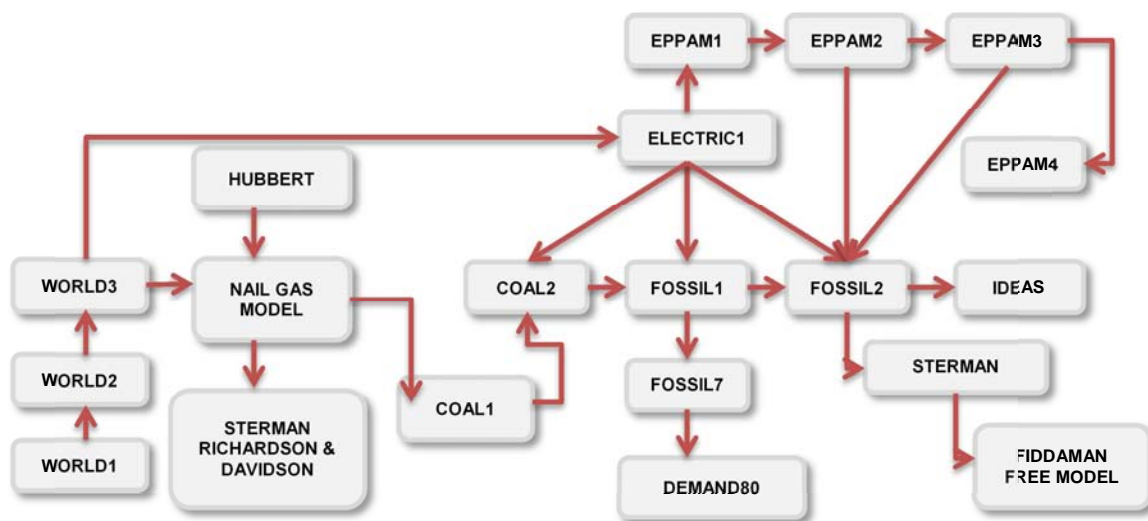


Figure 5: Intellectual Lineage of System Dynamics in Energy Modelling (Teufel, Miller, Genoese, & Fichtner)

Shortcomings in the FOSSIL2 model (such as the lack of important feedbacks and causal relations between the energy sector and the larger economy) resulted in Sterman's investigation of the dynamics of energy-economy interactions during the energy transition.

Sterman's system dynamics energy model was ground breaking since it was the first model that captured the energy-economy interactions. It was then in 1997 when Tom Fiddaman recognized that, although the source constraints (i.e. oil and gas) on the energy-economy system had been investigated by energy modellers, sink constraints (i.e. climate change) had not been accounted for (Fiddaman, 1997).

This led to the creation of the FREE (Feedback-Rich Energy Economy) model (Fiddaman, 1998). The FREE model was unique in that it explored endogenous technological change and bounded rational decision making with time delays and biases, not previously explored in a climate change context.

The world modelling projects also acted as a stimulus for Andrew Ford's study of the U.S. electric power industry and gave rise to the ELECTRIC1 model, one in a series of system dynamics electric utility models used to build the Electric Utility Policy and Planning Model (EPPAM) models and their variations (Ford & Yabroff, 1979). Ford's work set the stage for extensive system dynamics work that was used by utility managers for strategic planning (Teufel, Miller, Genoese, & Fichtner, 2013).

In South Africa, system dynamics is still in its nascent stages of application but has nevertheless been successfully used by various institutes in disciplines such as new technology impacts; sustainability (specifically climate change and biofuels); and renewables. Eskom Holdings especially has developed skills and successfully applied the methodology in raw water modelling (Raghu & Pillay, 2013), scenario analysis and electricity distribution reliability studies (Pillay, Webb, Booyens, & Von Berg, 2012).

The next section discusses the main elements and tools that should be considered in system dynamics modelling approach.

2.5.3 ELEMENTS OF SYSTEMS DYNAMICS MODELLING

Formal models using a system dynamics approach are expressed as stock flow diagrams (Takahashi, 2003); however, this step should be preceded by the development of causal loop diagram(s) or influence diagrams to structure and conceptualise the problem.

Causality is when two variables are linked by "*a chain of events each directly depending on its predecessor*" (Halper & Pearl, 2005). A causal loop diagram (CLD) shows the influences

and relationships between different parts of a system and assists in supporting systems thinking by showing that reality is composed of circular influence instead of linear influence structures (Haraldsson, 2000). These influences can either be negative (opposite direction) or positive (same direction) (Roberts, 1983). Variables in a CLD are both a cause and an effect and although the concept of constructing these diagrams appears relatively arbitrary, they are often incorrectly developed and instead of showing direction, causality and feedback; these end up being “spaghetti” diagrams⁴. Spaghetti diagrams use continuous flow lines that trace the path of an item or product or activity through a process (Bialek, Duffy, & Moran, 2009).

In addition to constructing CLDs, it is important to understand the system being studied by looking at historic data and trends, also referred to as historical reference modes (Sterman, 2000). Randers (1980) describes a reference mode as “... a graphical or verbal description of the social process of interest. The reference mode of a model under development can be stated by drawing a graph of the expected behaviour of major variables... Often the reference mode encompasses different possible time paths for the model variables”.

Historical reference modes become essential during the formulation of the stock flow feedback diagrams since they can provide clues as to what system behaviours could potentially arise. In addition to this, model runs can be compared against trends obtained from the historical reference modes as an indication of how accurate the model is or whether rework is required (Albin, 1997).

Behaviour modes and defining boundaries are also critical in system dynamics modelling. Every feedback system has a closed boundary which must be clearly defined and which contains all the variables in the final model (Albin, 1997). The variables may be endogenous (determined within the system of equations representing the real world) or exogenous (whose value is determined by variables outside the causal system under study) (Nagler, 1999). If not clearly defined, the model tends toward detailed complexity which distinguished from dynamic complexity. Detailed complexity is linked to the level of detail in system architecture maps while dynamic complexity is relevant when short-term and long-term effects are different (Melton, 2004; Senge, 1990).

⁴ Spaghetti diagrams are also known as “physical process maps” or “point-to-point flow charts” or “work-flow” diagrams containing all conceivable parameters relevant to a system. The expansive scope of variables seldom allows useful cause-effect or primary behavioural insights – the key objective of CLDs

Despite the usefulness of CLDs and historical reference modes, stock flow structures (as illustrated in Figure 6) depict dynamic system behaviour based on the “*Principle of accumulation*”⁵. These stock flow structures are important and simply illustrate that the dynamics behaviour in a system arises when flows accumulate in stocks. Sometimes, they are not always understood in which case they are referred to as “*stock flow failure*” by Cronin, Gonzalez & Sterman (2009). The equation commonly used in system dynamics models (i.e. $\text{Outflow} = \text{Rate at which the stock depletes}$) to determine the stock output is not often known and understood by decision makers (Jacobs, Bleijenbergh, & Vennix, 2011). It is thus important that the elements or primary components that make up a stock flow diagram are explained (Figure 6, Table 2) (Sterman, 2000).

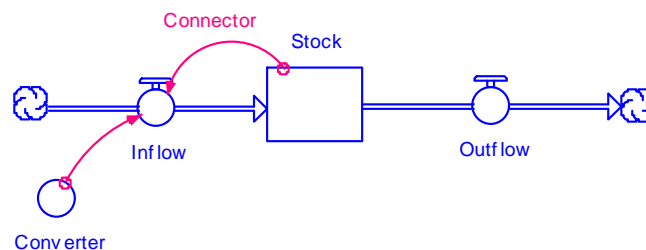


Figure 6: Illustrative Stock Flow Diagram

COMPONENT	DEFINITION	SYMBOL
STOCK	It is usually a noun. It can accumulate/ deplete things and provide systems with memory, besides having the ability to decouple flows and create disequilibrium dynamics which more closely represent real system behaviour. Stocks can only change through flows.	
FLOWS	It is usually a verb. Determines rate of change. Could be a bi-flow or uni-flow (inflow or an outflow). An inflow adds a certain quantity to the initial level of the stock. The outflow determines rate of change, by removing a certain quantity from the initial level of the stock. Not all flows need to be physical, they may also be information related flows. Flows could also be bi-flows, which can take on negative values and flow in either direction.	
CONVERTERS	Could be constants or time series data inputs or equations and could be connected to other equations that can be constructed to define relationships between variables.	

⁵ Principle of Accumulation states that “all dynamic behaviour in the world occurs when flows accumulate in stocks” (System Dynamics Society, 2013)

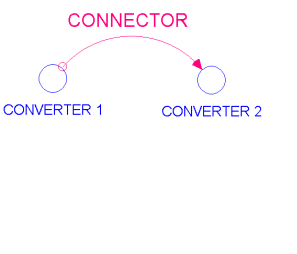
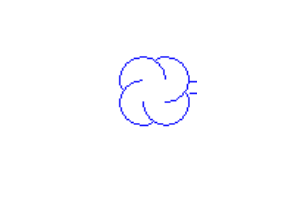

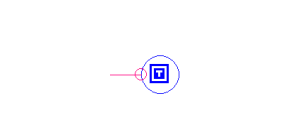
CONNECTORS	Connectors either contain a constant value or may be used to apply to an equation and convert a set of inputs into an output. They are links that carry information about the current state of the system (the stock value) or any other system variable to the variables that make the system change (the flow) (Martin, 1997).	
CLOUDS	A cloud represents the boundary of the system (Schools, 2003). A cloud attached to the inflow is known as a source and if attached to the outflow is known as a sink. The source and sink can be infinite when undefined by variable relationships or mathematical boundaries.	
GHOSTED VARIABLE	A ghosted variable (illustrated by broken lines) indicate replicated component for use as an input variable elsewhere in the model.	
SWITCH	A switch can be assigned to one or more converters and allows the user the ability to include or exclude the variable behind that converter.	

Table 2: Components of System Dynamics Modelling

When the effects in one variable cause a change in another variable and the effects then trail back to the first variable, this is referred to as feedback (Monga, 2001). Feedback could be positive or self-reinforcing (amplifies system changes) or they could be negative or self-correcting (balances the system changes and provides equilibrium by opposing the changes taking place in the system).

Depending on the type of stock flow feedback structure, a system has certain patterns of behaviour, of which the three fundamental modes are: exponential growth, goal seeking and oscillation (Sterman, 2000). If the characteristic feedback being displayed is understood, corrective actions i.e. policy changes can be made and strategic decisions taken that will correct or normalise the system behaviour. This is clearly not possible, without understanding behaviour modes.

The following section explains the modelling methodology used in this study.

2.6 METHODOLOGY

The previous section provides a detailed literature review on existing research linked to factors that are closely correlated with income inequality, with an emphasis on demographic and labour market driving forces. A review was also conducted on systems thinking, as well as system dynamics modelling and related considerations for energy modelling. Based on the understanding of the literature, the following methodology was adopted to meet the research objectives described in Section 1.3.

As part of the Model Development and Model Structure (Chapter 3), a causal loop diagram was constructed as well as an integrated high-level architectural map/ system architecture map (SAM) of the variables and interacting systems that impact income distribution (Longbin, 2007). Some of the demographic and macroeconomic factors from Kaasa's comprehensive lists were considered in this study and although the validity of the excluded driving forces on this list is acknowledged, it is beyond the scope of this study.

The SAM shows the overall architecture of flows between variables and provides an alternative representation of the dynamic modelling variables without detailed mathematical equations and stock flow feedback diagrams used in system dynamics modelling. In order to understand the dynamics within the economic sectors, Giampietro et al. (2009) used hierarchical and multi-scale analysis where the sum of each sub-level should equate to the quantities in the level immediately above it.

A model boundary chart with endogenous, exogenous and excluded variables was constructed. The model boundary chart is important for understanding the constraints and limitations of the model and it also helps to communicate the boundary of the model and to represent its causal structure (Longbin, 2007). Excluded variables highlighted those causalities not included in the modelling boundary.

The stock flow feedback diagrams using STELLA software were constructed for different sectors together with relevant equations to be simulated. This provided the detailed representation of the system being modelled that generated future patterns of behaviour.

Data was collected during the analysis to establish the historical reference modes but also during the model construction to test the model validity. The following differential equation forms the basis of the calculations conducted in STELLA and is automatically written into the Equation layer of the software program as the model structure was developed with the

associated mathematical relationships and equations. The derivative equation is described as a net change in stock or the inflow less the outflow.

$$Stock(t) = Stock(t - dt) + (Inflow_rate - Outflow_rate) \times dt$$

STELLA uses Runge-Kutta or Euler's integration method and for this project, the run specifications were set on the Euler integration method since the model structure contained discrete event logic that is not consistent with the Runge-Kutta integration.

There were two model structures that were constructed in this study. The first simulator structure was based on Stats SA 2005/6 income and expenditure data and calculated the Gini coefficient based on changes in variables such as free services, household sizes and social grants (known as the Static model). Besides helping to understand the intricacies of redistributive measures introduced through various national policies and its perceived effectiveness, it was important to fully interrogate the data and find gaps for understanding the impact and causalities of different variables on income distribution in South Africa that may not have been covered in prior research.

The first structure allowed an understanding of changes in social grants which included the following categories:

- Pension from previous employment
- Annuities from own investment
- Old age pensions
- Disability grants
- Family and other allowances

Stats SA 2005/6 income and expenditure data (2008) provides an average number of household members per decile from deciles 1 (low income households) to 10 (high income households). The average number of household members per decile could potentially change due to system shocks such as population explosion or a reduction in population due to health risks/diseases. The type of disease and magnitude that could affect household numbers was varied to facilitate sensitivity analysis, but varying the average household size was based on the premise that health or social drivers are at play. No equivalence scales⁶ were used to differentiate between income earners and income receivers within households.

⁶ Equivalence scales assign different weights to adults, dependents and children in a household to emphasize scale economies in a household.

The assumption was that income and consumption within the households were equally shared among household members.

The second structure was based on time series information and linked the economic sector, demographics, income distribution and related residential consumption together (known as the Dynamic model). Although household income across deciles was calculated from 1994 to 2035, some issues that occurred over time such as ageing, household movements and change in jobs were not considered. The time horizon for the model was set to cover 41 years (from 1994 until 2035) as an ideal balance for data consistency. Any year earlier than 1994 did not enhance the value of the projected modelling trends while 2035 was chosen as the model run end date to cover the Integrated Resource Plan period (ISMO, 2011).

Model results include a base scenario and then three additional scenarios for both structures although many more scenarios were possible. Model verification was done by a series of test runs using different scenarios and configuring calculated outputs in support of the modelling objectives. Model validation then followed to ensure that the model correctly represented reality by calibrating the model through various iterations and comparing the model behaviour to historical data, similar to the approach followed by Wu (1991).

When comparing computer simulated and empirical patterns of behaviour, there may be mismatches. Understanding why behaviours are divergent is necessary. There are several reasons for divergence in behaviour between modelled and empirical results including:

- There could be non-linear causal relations between variables. The sensitivity of the model's behaviour to changes in parameters need to be checked so ensure that the simulated model (with new calibration) improves the match between simulated and observed behaviour.
- In some instances, the reason for the difference could also be that the real system behaviour may contain short-term perturbations that are not explicitly modelled or considered in the model with structural considerations aimed at long-term trends.
- The causal structure of the theory and the causal relationship affecting the real system may not be isomorphic in some respects.

The simulation test runs were then used to draw conclusions using the research tool STELLA (the equivalent of iThink⁷), which was the first icon-based programme based on Forrester's earlier work on stock-flow structures. It was the first to accumulate models and knowledge around the work that led to the introduction of system dynamics into sustainability contexts, therefore, arguably, the richest in historical context. Earlier software such as Dynamo involved command line scripting as opposed to icon-based programming, increasing the time involved in setting objective functions, parameters, mathematical equations and initial conditions. Other commonly used programs for system dynamics modelling include PowerSim Studio, Vensim, Simulink and AnyLogic, the choice of which depends on the modeller's needs and application.

⁷ iThink and STELLA are functionally the same, however, STELLA is targeted toward educational and research settings while iThink is targeted for use in business settings.

CHAPTER 3: MODEL DEVELOPMENT AND MODEL STRUCTURE

In this chapter, the main features and model structures of the income distribution system dynamics simulator are explained. A summary of the key mathematical equations is provided, followed by a qualitative representation of the system problem using a causal loop diagram. This is followed by a model boundary chart with the key variables included in the model, as well as a subsystem or map of the structure of the model. This chapter is concluded by presenting the STELLA stock flow feedback structures and related equations used.

3.1 MATHEMATICAL PREREQUISITES

The stock flow feedback structures developed using STELLA software required causal mapping and linkages between different system variables with clearly defined mathematical relationships and equations. The two key mathematical relationships that were used in trending the long-term pattern of behaviour of the system included:

- The logistics curve (where system behaviour was characterised by exponential growth and stabilization towards a non-zero value), and
- An exponential function was used to splice the last point in a time series of empirical data with an extrapolated curve that had been fitted to that data.

3.1.1 THE LOGISTICS S-SHAPED GROWTH CURVE

The S-shaped logistics growth model has been applied to a variety of systems in the biological and socio-technical regimes (Meyer, 1994). This type of behaviour starts off with an initial growth value which (after a certain amount of time) is limited by the carrying capacity of the system and negative feedback loops start to dominate which result in goal seeking behaviour, yielding an overall S-shaped growth.

In this study, asymptotic convergent S-shaped growth (where the limit is approached without overshoot) was used for trends that represent efficiency factors such as energy efficiency and has also been used to model transitional behaviour in parameters such as the wage regimes. It is also in keeping with the sustainability approach to modelling energy systems

proposed by Giampietro et al. (2012). The equations for S-shaped growth were constructed using MS Excel after obtaining the historical data from 1994.

Nel's (2011) approach of using an S-curve equation that has the flexibility to allow declining trends following asymptotic conversion to lower values is made possible through specifying a negative value for U_1 in the following S-curve equation and was used in this study for projecting future trends in parameters with declining trends that stabilize at a final value:

$$P(t) = U_0 + \frac{U_1}{1 + \exp[-c(t-t_0)]} \quad \text{Equation 1}$$

Where: $P(t)$ is a function of time t

U_0 is the zero offset

U_1 is the ultimate increase (or decrease) above U_0 , modelled by the s-curve

c is a growth rate exponent that determines the maximum slope of the s-curve

t_0 is the time at which the maximum slope is reached (inflection point)

In this study, fitting the equation above to empirical household income data was not possible through linear regression due to the non-linear relationship between the dependent and independent variables. Nel (2011) proposed using a mathematical optimisation routine to minimise the error function between the empirical data and the function values by varying the variables (U_0 , U_1 , c and t_0) in Equation 1. This mathematical approach was used for calculating future trends of the following variables:

- GDP values for the residential and economic sectors
- Population
- Electricity consumption per GDP
- Wages per employed
- Employment per GDP
- Taxes per household current income.

Figure 7 provides long-term smooth plots which disregard short-term variability in some cases, with a discontinuity between the actual empirical data and the simulated future behaviour. In this case, Nel's (2011) approach of using an exponential decay model for trending was used, as explained in the next sub-section.

3.1.2 THE EXPONENTIAL DECAY MODEL

The system behaviour described by the model is characterised by exponential growth and stabilisation and allows the simulated results to depict the realistic discontinuity in actual empirical results by “decaying” the discontinuity over time, observed in Figure 7.

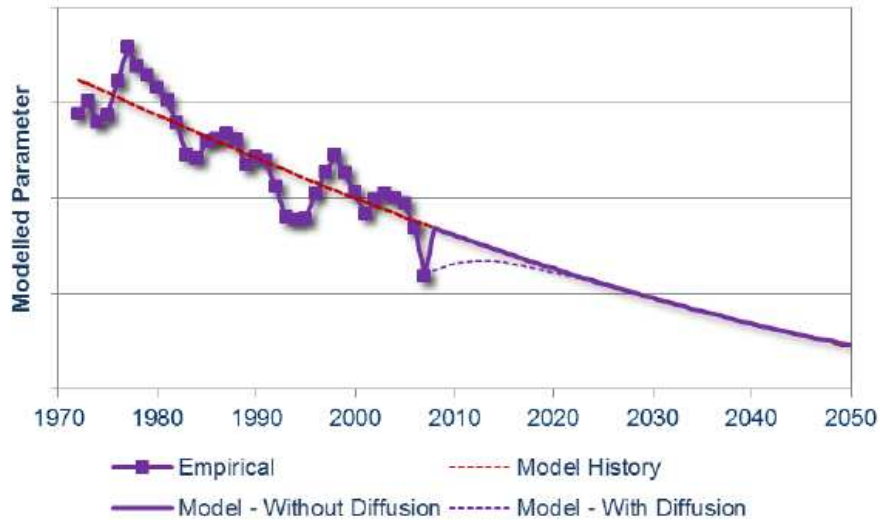


Figure 7: Diffusion Model

The equation used for this purpose follows:

$$M^*(t) = M(t) - (M_T - E_T) \exp\left[-\frac{(t - T)}{\alpha}\right] \quad \text{Equation 2}$$

Where: $M^*(t)$ is the diffusion corrected modelled function of time t

$M(t)$ is the regression-modelled function of time t

T is the time for the last recorded measured data point

E_T is the last recorded measured data point

M_T is the regression model result for time T

α is the decay exponent

3.1.3 SIMULATION ALGORITHMS USED IN STELLA

As discussed in the Methodology Section Equation 3 formed the basis of the calculations conducted in STELLA:

$$Stock(t) = Stock(t - dt) + (Inflow_rate - Outflow_rate) \times dt \quad \text{Equation 3}$$

STELLA uses simulation algorithms such as Runge-Kutta or Euler's integration method to calculate the levels of the stocks. The Runge-Kutta method was designed to be used when there are continuous systems with oscillatory behaviour, however, since IF-THEN-ELSE logic was used to generate integer values and 0-1 switching in this simulation project, Euler's method was chosen, as recommended by the Stella support manual. The unit of time in the model Run Specs dialog was set as years with a time step between calculations (DT) of 0.33 across the span of a year. DT in the integration time step that is used in the selected numerical integration scheme i.e. the time step for which area calculations (of the rectangles under the curves of flow over time) are computed. The smaller the time step DT (in other words the greater the number of area calculations of rectangles), the greater is the resolution of numerical integration and the greater the accuracy. However, a trade-off must be made between calculation accuracy and the number of calculations so that an unnecessarily large number of area calculations are not done.

3.2 CONTEXTUALIZING THE PROBLEM

The techniques that were used to describe and contextualize the problem with its integrated elements involved the use of a causal loop diagram, a model boundary chart and a system architecture map, all of which are explained below.

3.2.1 CAUSAL LOOP DIAGRAM (CLD)

In order to provide a visual representation of the high level dynamics that impact on income distribution (based on the literature survey that was completed), the causal loop diagram in Figure 8 was constructed which took high level driving forces into account (urbanization, GDP, demographic development, and employment). The CLD is a focused representation of those factors that were included in the scope of this project.

In a CLD, the causal link from variable A to variable B may be positive or it may be negative. If it is positive, it means that variable A adds to variable B or a change in variable A results in a change in variable B in the same direction. If it is negative, then A subtracts from B or a change in variable A produces a change in variable B in the opposite direction. If the feedback loop containing 2 or more variables has an even number of negative causal links, then it is a positive or reinforcing loop denoted by R. If it contains an odd number of causal links, it is known as a negative or balancing loop denoted by B.

Consistency was sought with research on the development sequence of economies such as reported by Rostow (Rostow, 1960). These stages of economic growth can also be categorised as pre-commercial, commercial (division of labour between primary and secondary economic activities – urbanization), industrialization and knowledge. In Figure 8, $GDP_{P\&S}$ refers to the GDP for the Primary and Secondary economic sectors while GDP_T refers to GDP for the Tertiary sector.

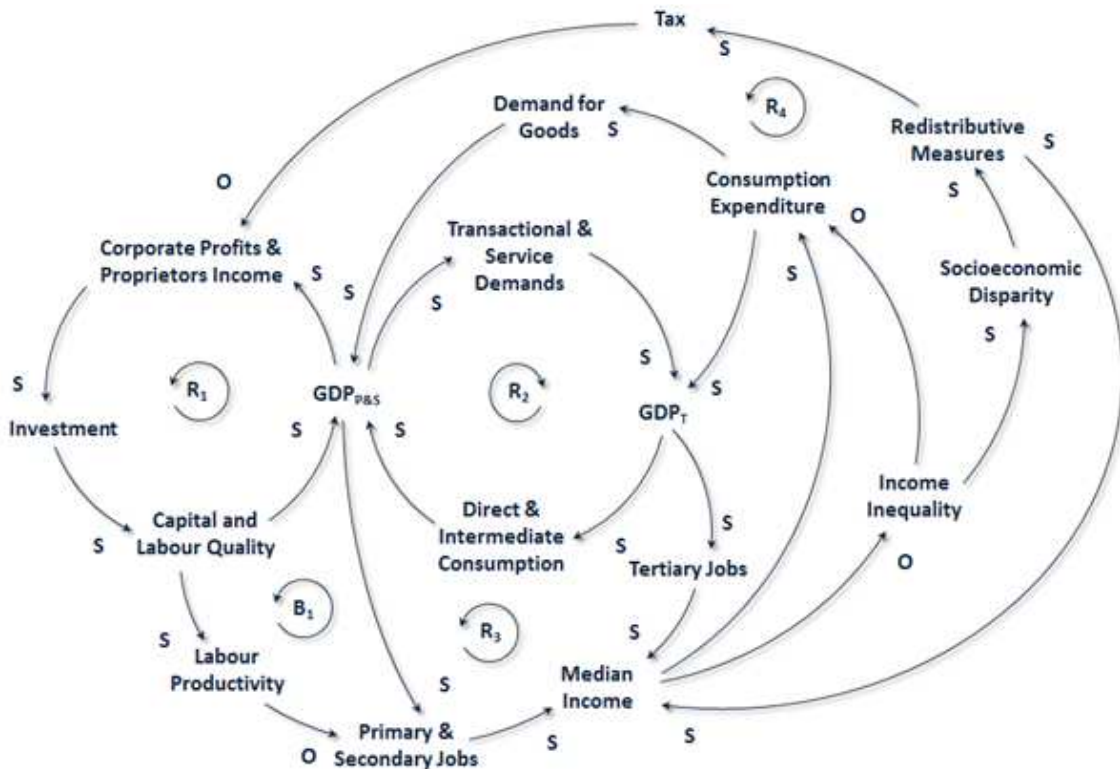


Figure 8: Overall Causal Loop Diagram

The output in an economy is dependent on labour and capital. Rostow (1960) introduced the concept of five stages economic growth in societies:

- The traditional society - society's structure allows for limited production functions, outputs are not traded but consumed by producers.
- The preconditions for take-off – heightened by increased specialization which generates surpluses for trading in the face of increasing incomes, savings and investment growth.
- The take-off – marks the industrialization period where workers transition from the agricultural (primary) sector to the manufacturing (secondary) sector.
- The drive to maturity – urbanization takes off and technological innovation provides more investment opportunities with a decreased reliance on imports.
- The age of high mass consumption – high levels of economic activity now exist with the service sector now gaining dominance.

The developments of the primary and secondary sectors are capital intensive and require a concentration of wealth to start off. One form of wealth concentration is through corporate profits and proprietor's income (the role of financial services is covered in the tertiary sector). Wealth concentration enables the investments required for upgrading and maintaining the quality of labour and capital, which in turn increases productivity leading to further growth in the primary and secondary economies. This reinforcing cycle (R1) is an essential element of diversified economies and covers the production elements of only the primary and secondary sector. Demand stems from the consumption by employees (spending wages) and the intermediate demand of goods (consumed in the production process).

The expansion of the primary and secondary sector GDP (GDP_{PS}) leads to an increase in demands for financial services (to facilitate a transactional environment) and for a services sector (both personal services and free labour for specialised economic activities) and to apply knowledge-based services for the improvement of production processes such as research or maintenance. This expansion leads to growth in the tertiary sector and an increase in direct demand for manufactured goods and services (affordable through the disposable income of workers in the secondary sector) as well as for intermediate goods

(consumed in the tertiary sector economic activities). This reinforcing cycle (R2) expands as a result of surplus production from the primary and secondary sector.

The primary factor in median income is employment. Wage disparity between economic sectors is a secondary influence. Employment (jobs) and average income are affected through several mechanisms:

- Firstly, primary and secondary economy jobs increase as the sectors increase and the same goes for the tertiary sector.
- Secondly, increases in the quality of capital and labour leads to deepening of capital (less labour required in proportion to capital) and a relative decline in primary and secondary sector jobs.

As a primary factor of median income, total employment bears the most direct influence on median income. Median income, together with income inequality leads to an increase in demand for goods and services and an expansion of GDP at the production boundary (personal expenditure needs to saturate to some degree so that further increases in disposable income does not necessarily lead to increased demand for goods and services). Income inequality feeds back into the system in terms of the regulation that socioeconomic disparity exerts through redistributive measures such as social grants and free basic services. These redistributive measures have the effect of adjusting median income while reducing corporate profits and proprietor's income with a slowdown in growth.

Before evaluating where drivers such as demographics fit into the system, a few feedback loops are identified. Firstly, there is a balancing loop (B1) through the primary & secondary sector system (R1) through one of several mechanisms (split from median Income). Secondly, there is a reinforcing loop (R3) through the primary & secondary sector system (R1) with a branch through the tertiary system (R2). A similar reinforcing loop feeds back directly to median income from GDP_T . Thirdly, there is a reinforcing loop, R4, related to redistributive measures through both R1 and R2 with a split at GDP_{PS} . Using this framework, other relevant drivers and parameters are highlighted.

The CLD was important in creating a common qualitative platform for discussion of the perceived thoughts and assumptions that impact income distribution and residential electricity consumption in South Africa.

3.2.2. MODEL BOUNDARY CHART

Table 3 lists exogenous (not affected by the state/ feedback loops of the model), endogenous (dependent on the system state) and excluded (not taken into account in the model) variables for this project.

EXOGENOUS VARIABLES	ENDOGENOUS VARIABLES	EXCLUDED VARIABLES
<ul style="list-style-type: none"> • GDP growth • Population growth • Free services 	<ul style="list-style-type: none"> • Gini coefficient • Residential electricity consumption • Dependency Ratio • Disposable income • Wages • Employment • Electricity 	<ul style="list-style-type: none"> • Government's expenditure and debt • Changes in the exchange rate • Inflation • Urbanisation • Level of education • Health of population

Table 3: Model Boundary Chart of the Income Distribution Variables

The following model variables (shown in greater detail in the system architecture map in Figure 9) were not considered in this study but could be included should the model be further extended:

- healthcare,
- level of education,
- urbanization,
- government debt,
- government budget,
- inflation,
- foreign reserves, and
- investments.

3.2.3 SYSTEM ARCHITECTURE MAP

The system architecture map (SAM) (Figure 9 & Figure 10) shows the overall architecture of the income distribution system as well as the interacting driving forces. These diagrams were useful in understanding the allocation and breakdown of the South African societal labour force and its contribution to the economy.

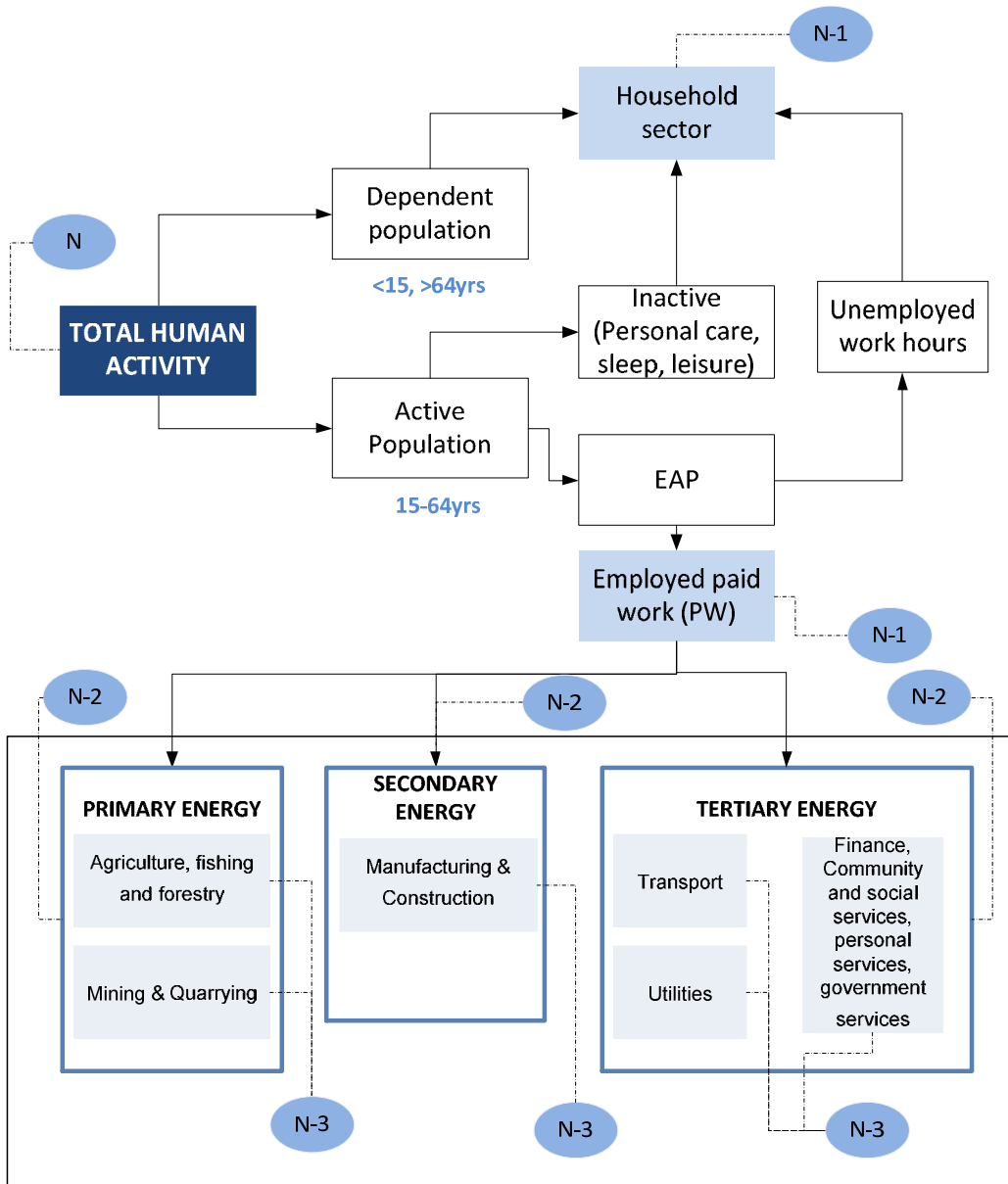


Figure 9: System architecture map showing the hierarchical breakdown of levels

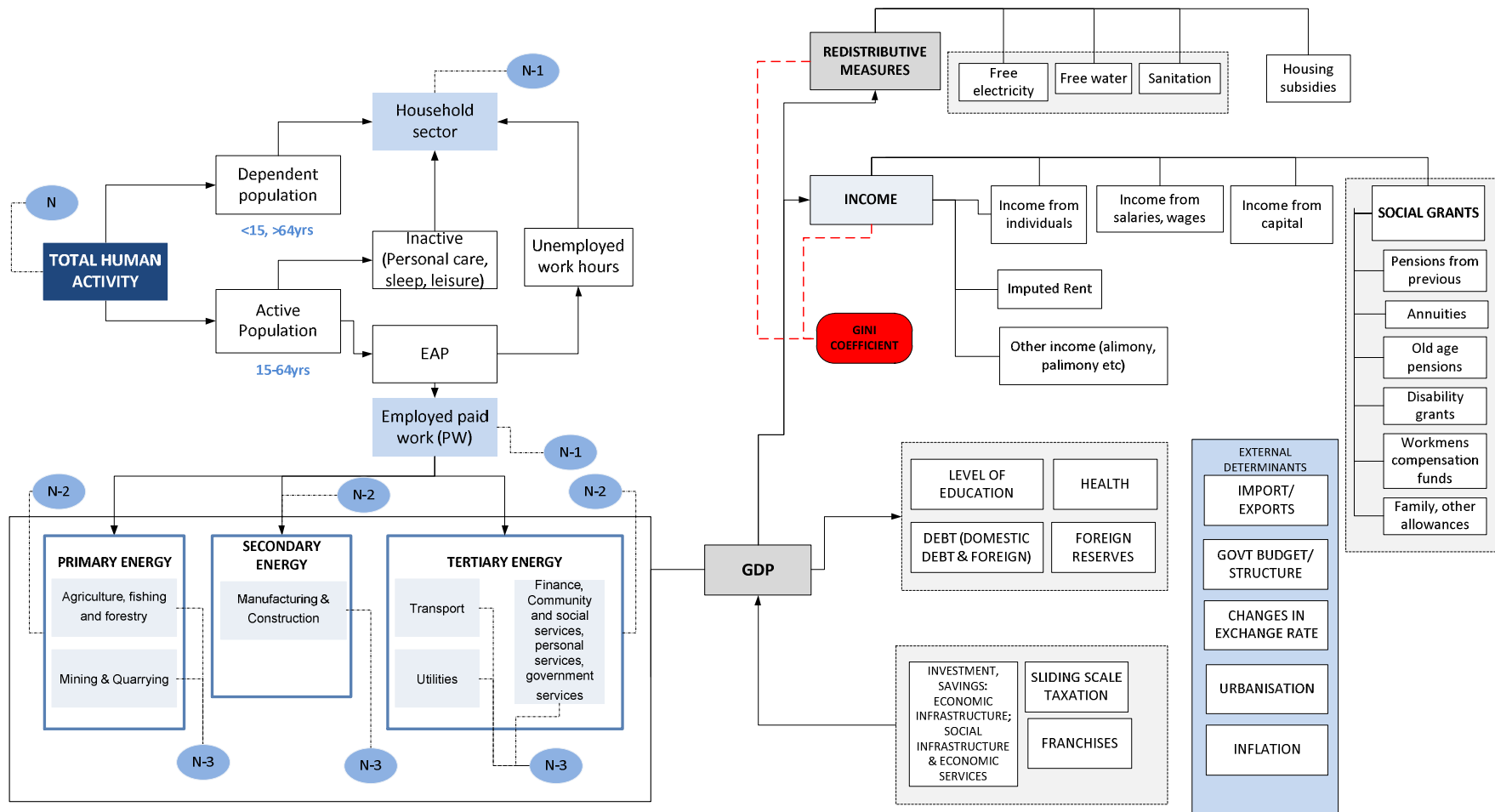


Figure 10: System Architecture Map showing driving forces that impact HH expenditure

Hierarchical analysis was adopted which involved breaking down total hours of activity spent by society (also referred to as Total Human Activity – THA) into various analysis levels:

- n: the level for the human activity for the entire society (there are 8,760 hours per person in a year in a society),
- n-1 : the distinction between the household sector (involved in consumption) and the paid work sector,
- n-2: level where the sectors were selected (primary energy, secondary energy and tertiary energy sectors).

The sectors are based on the following descriptions (Chinembiri, 2010):

- Primary energy (PE): included economic sectors that dealt with the extraction of raw materials from natural resources to be used in the other economic sectors.
- Secondary energy (SE): included outputs from the primary sector that were developed into finished/ saleable goods.
- Tertiary energy (TE): this sector provided services to other businesses as well as final consumers.

It was possible with the multi-level, multi-scale analysis approach to understand:

- internal constraints,
- leverage points to effect change linked to population structures, and the
- causal relationship with activities in the production sectors.

By calculating the flow of added value generated through paid work and expressing economic performance as GDP per hour of labour supply instead of relying on intensive variables such as GDP per capita, it is apparent how the changes in age structure and related demographics impacted on the labour market.

Level n	Level n-1	Level n-2	Level n-3
Society – Total Human Activity (THA)	Household sector (HH)		
	Paid Work sector (PW)	Primary energy (PE)	Agriculture, fishing and forestry
			Mining & Quarrying
		Secondary energy (SE)	Manufacturing & Construction
		Tertiary energy (TE)	Utilities
			Transport
Finance, Community and social services, personal services, government services (rest of the tertiary sector)			

Table 4: Hierarchical Breakdown of Human Activity in Society (Giampietro M.)

The detailed steps of the process that was followed to calculate the flow of value added per hour of paid work are as follows:

1. The economically active population (EAP) summed the employed and the unemployed (unemployed also includes the population looking for a job) stocks which included the 15-64 year age group.
2. A portion of the active population (15-64 year age group) included an inactive group (students, pensioners, discouraged work seekers, and people without jobs) engaged in leisure, sleep and personal care.
3. While the employed paid work (PW) sector reflected the economic sectors that generated GDP, the difference between the total population and the employed paid work sector provided the household (HH) sector (also known as the dependent population and included the age groups <15 and >64).
4. The GDP per capita was calculated as the GDP stock divided by the population stock.
5. The next step was to calculate the dependency ratio.
6. The dependency ratio was the household sector stock divided by the employment stock.
7. The next calculation included available manhours.
8. To calculate fraction human activity for paid work (employment) per total human activity (8,760 hours); the employment stock was divided by the population stock.
9. The paid work hours per year was then the total human activity hours multiplied by the fraction of the population in the paid work (PW) sector.
10. Finally, the flow of added value generated in paid work was then calculated by dividing the GDP by the paid work in hours per year.

The total GDP (in basic prices at constant year 2005 Rand) was aggregated from the various economic sectors with data obtained from the South African Reserve Bank (SARB, 2012).

3.3 STOCK FLOW FEEDBACK STRUCTURES

This section of the report deals with explaining all the model structures that were built using STELLA systems dynamics modelling software. It includes elaboration and explanations on the structures for each model in Table 5. The Static Model (SM) and the Dynamic Model (DM) are not causally linked and hence the structures have been differentiated from each other.

STATIC MODEL (SM)		DYNAMIC MODEL (DM)	
3.3.1	Household income categories by main income group.	3.3.3	Population and GDP.
3.3.2	Endogenously calculated Gini coefficient.	3.3.4	Dependency ratios and the labour market.
		3.3.5	Per economic sector: total electricity, total employment and total wages.
		3.3.6	Household Final Consumption Expenditure (FCE).
		3.3.7	Disposable household income.
		3.3.8	Residential electricity consumption with variable Gini coefficients.

Table 5: Model Structures Developed using Stella Software

3.3.1 STATIC MODEL (SM)

3.3.1.1 HOUSEHOLD INCOME BY MAIN INCOME GROUP (SM)

The average household income (based on STATS SA 2005/6 data) was divided into ten population income groups (or deciles) where decile 1 includes the poorest 10% of households and decile 10 includes the richest 10% of households. Data for the main

income⁸ group for expenditure deciles and income deciles was used to calculate and determine any discrepancies in the calculated values of the Gini coefficients.

The average household income was broken up into income categories to make the Gini coefficient a dynamic endogenous calculation. The income variables included (as categorized by Stats SA) income from:

- Work (include salaries & wages; self-employment; business income)
- Capital (includes interest; dividends; rent income; royalties)
- Free services (free water; electricity; sanitation)
- Social grants (includes old age and war pensions; disability grants; family and other allowances; various funds such as workmen’s compensation)
- Other income (alimony, palimony and other allowances; other income from individuals; benefits, donations and gifts, and cash; tax refunds received)
- Imputed rent.

Figure 11 shows the variables ‘Capital’ and ‘Free Services’ which contain switches that allow the user to activate or deactivate the inclusion of these income categories in the average household income total. The variables in Figure 12 that appear to have several overlaying circles imply arrays which allow a single variable to be used for different income deciles which belong to a particular income category, instead of creating unnecessarily many variables. In the case of the single arrayed variable ‘Average HH Income from Capital’, the variable has the following values Table 6:

AVERAGE HOUSEHOLD INCOME FROM CAPITAL (RANDS)									
Decile	Decile	Decile	Decile	Decile	Decile	Decile	Decile	Decile	Decile
1	2	3	4	5	6	7	8	9	10
40	30	38	69	77	124	193	573	923	6610

Table 6: Average HH Income from Capital for the Income Deciles (StatsSA 2005/6)

The ghosted variable ‘Average HH income from Free Services’ in Figure 11 indicates a replica of another variable and has no independent identity. It is originally linked to the structure in Figure 12.

⁸ The main income group is as defined by Stats SA - would be the highest level of aggregated data for incomes and expenditures.

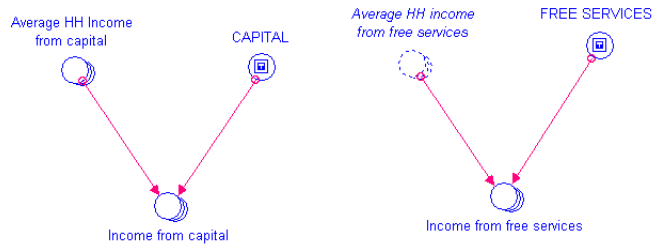


Figure 11: HH Income Variables (Capital and Free Services)

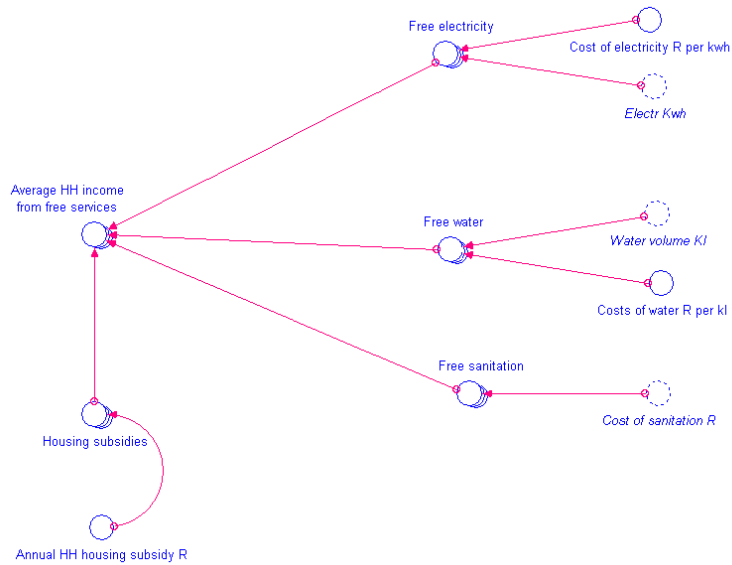


Figure 12: Average HH Income from Free Services Model Structure

Free services data was allocated to income deciles 1, 2 and 3. The quantitative amounts of service volume and related price were used as follows:

	FREE SERVICE	QUANTITY PER MONTH PER HOUSEHOLD	COST (R)	AVERAGE VALUE (R) PER HOUSEHOLD
1	Basic water	6 kl	5.12/kl for 6-12kl	33.72
2	Electricity	50 kWh	0.70 per kWh	27.01
3	Sanitation			33.72

Table 7: Values Used in Calculations for Free Services (Adél Bosch)

Similar structures to those in Figure 11 were constructed for the other contributors to household income.

3.3.1.2 CALCULATING THE GINI COEFFICIENT (SM)

Figure 13 shows the variables that were used in calculating the Gini coefficient values in the model structure (based on STATS SA 2005/6 data).

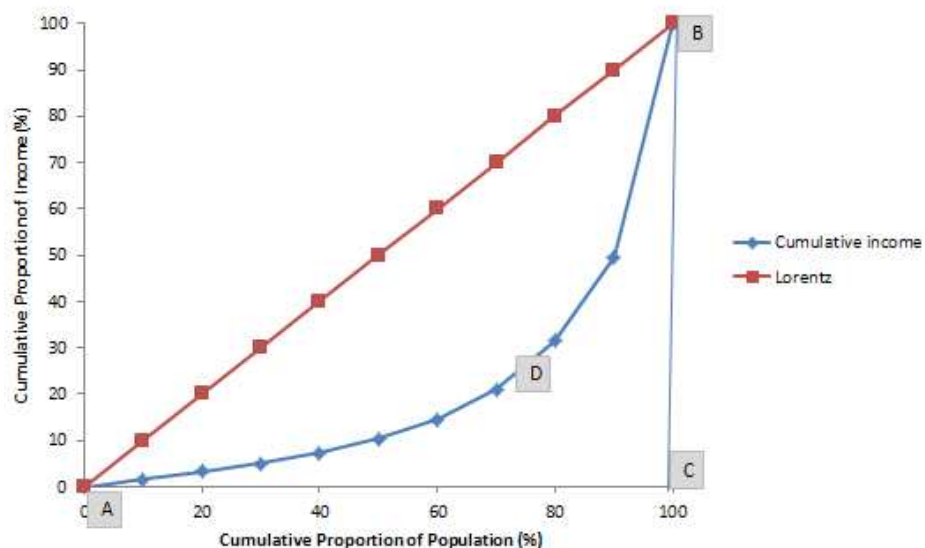


Figure 13: Calculating Gini Coefficient

The Gini coefficient is reflected on a graph of cumulative income vs. cumulative population that is accumulated from an ordered list of the population in ascending order with respect to income. An equal distribution of income would reflect a straight line (line AB in Figure 13) while an unequal distribution of income would follow a concave line below the straight line. With reference to Figure 13, the Gini coefficient is a ratio with the area between the straight line and the concave line as the numerator and the area between the straight line and the x-axis as the denominator (Equation 4):

$$Gini = \frac{Area\ ABD}{Area\ ABC} \quad \text{Equation 4}$$

First the denominator for Gini can be calculated. The maximum coordinates of the Lorenz curve is at point B (1, 1). The area ABC is thus a triangle with base length 1 and height (Equation 4).

The area ABD is equal to the total area ABC minus area ADBC (the sum of the areas of the polygons) shown in Figure 14. This is a numerical approximation and matches the resolution of statistical data available on income distribution surveys i.e. accuracy is not limited by the numerical approximation, but by the resolution of available statistical data.

The area of the triangle is:

$$Z_1 = \frac{P_1 I_1}{2}$$

The area of each trapezium is:

$$Z_i = \frac{(I_i + I_{i-1})(P_i - P_{i-1})}{2}$$

Since $I_0 = P_0 = 0$, the sum of all the areas is:

$$Z = \sum_{i=1}^n Z_i = \frac{1}{2} \sum_i [(I_i + I_{i-1})(P_i - P_{i-1})]$$

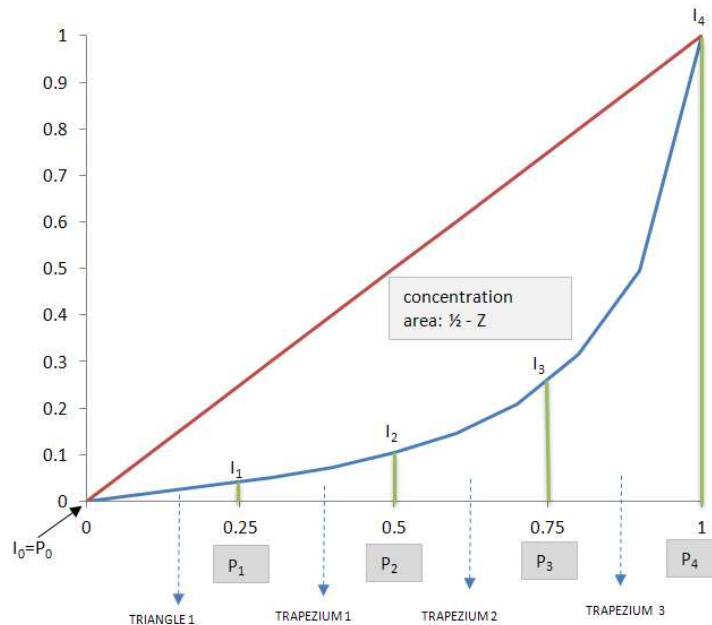


Figure 14: Calculating the Concentration Area

The value for Z is not the concentration value but the area under the Lorenz curve. The numerator for the Gini is then calculated from the maximum concentration area ($\frac{1}{2}$):

$$\text{Concentration area} = \frac{1}{2} - Z = \frac{1}{2} - \frac{1}{2} \sum_i [(I_i + I_{i-1})(P_i - P_{i-1})]$$

$$Gini = 1 - \sum_i [(I_i + I_{i-1})(P_i - P_{i-1})]$$

Thus, according to Equation 5, Gini is calculated as:

$$Gini = 1 - \sum_i [(I_i + I_{i-1})(P_i - P_{i-1})] \quad \text{Equation 5}$$

The household per capita income I_i plotted on the y axis was calculated by dividing the average HH income for each decile by the number of people in the household for that decile which for the dataset used (Table 8) was as follows:

AVERAGE NUMBER OF MEMBERS PER HOUSEHOLD (HH)									
Decile	Decile	Decile	Decile	Decile	Decile	Decile	Decile	Decile	Decile
1	2	3	4	5	6	7	8	9	10
2.8	3.3	3.8	4.4	4.7	4.9	4.6	4.4	3.8	3.6

Table 8: Average HH Members for the Income Deciles (StatsSA 2005/6)

3.3.2 DYNAMIC MODEL (DM)

3.3.2.1 POPULATION AND GDP (DM)

The model structures from section 3.3.2 onwards make use of time series data from 1994. Population and GDP are modelled as stocks (Figure 15). The inflows to the population stock include in-migration and births; while the outflows include out-migration and deaths. A biflow with GDP growth is linked to the GDP stock and is calculated by multiplying the annual change in GDP (growth fraction) by the GDP stock. The simplified demographic balancing Equation 6 forms the basis of the population projection and can be presented as follows:

$$P_{t+1} = P_t + (B_t - D_t) + (I_t - E_t) \quad \text{Equation 6}$$

- P_{t+1} : Population at time t+1
- P_t : Population at time t
- B_t : Number of births during interval
- D_t : Number of deaths during interval
- I_t : Number of immigrants during interval
- E_t : Number of emigrants during interval

The GDP per capita (Figure 15) was then calculated as the GDP stock (Equation) divided by the population stock where values for GDP were used at constant 2005 Rands.

The GDP fraction (Figure 15) was linked to a switch that allowed the user to select a constant rate at which the overall GDP for the economic sectors can change or a dynamic rate of change could be defined by the user as a different value per year, from 2012 onwards. The ghosted GDP fraction change was calculated from the stock GDP RM2005Y2 that sums all the GDP (RM2005) for the primary, secondary and tertiary sectors denoted by the converter GDP PS SS RS RM2005 (which is the sum of the GDP growth from the Primary Sector, the Secondary Sector and the Tertiary Sector).

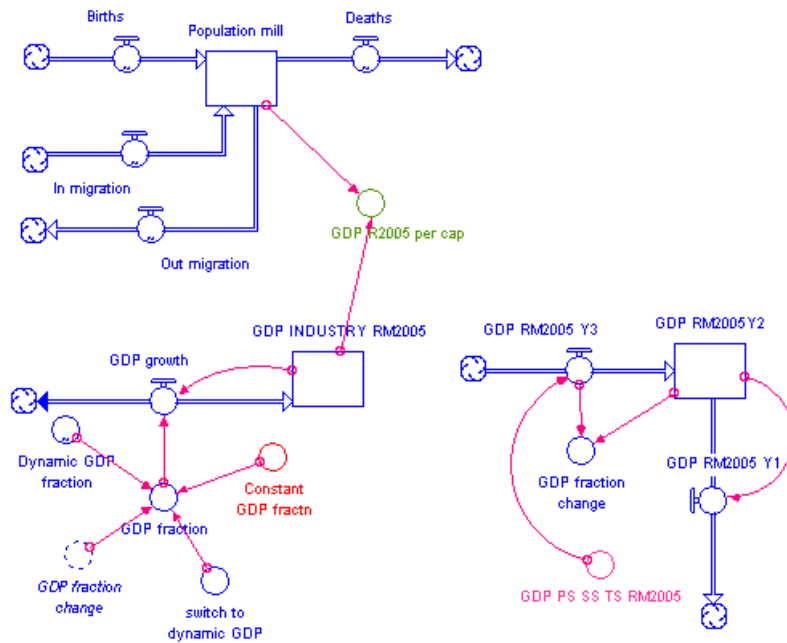


Figure 15: Population and GDP Stock Structure

INITIAL VARIABLE VALUES	UNIT	VALUE
Population in 1994	Millions	38.630
GDP in 1994	Rands (2005) Millions	982708

Table 9: Population (StatsSA, Labour Force Survey P0210) and GDP Equations (SARB)

$$Population(t) = Population(t - dt) + (Births + Immigration - Deaths - Emigration)$$

$$GDP(t) = GDP(t - dt) + (GDP\ growth\ rate) \times dt \quad \text{Equation 7}$$

3.3.2.2 LABOUR MARKET (DM)

Model structures were set up for the Labour Market (LM) dynamics and included the following stocks, generically referred to as Labour Market:

- Informal Employment,
- Formal Employment, and
- Unemployment.

The following Equation 8 applied to all the stocks for the Labour Market simulation algorithms:

$$LM_i(t) = LM(t - dt) + (LM\ growth\ rate) \times dt \quad \text{Equation 8}$$

Where: LM is the Labour Market variable
 LM could be Formal Employment or Informal Employment or Unemployment (as defined by Stats SA) (SAIRR, 2012)⁹
 LM growth is the rate at which the labour market stock grows.

The initial values for all the stocks that were calculated in Equation 8 are listed in Table 10.

⁹ Unemployed are those people that had not been working at the time of the survey, had actively looked for work or tried to start a business 4 weeks before the survey, had not actively looked for work 4 weeks before the survey but were starting at a definite date into the future. Informal employment includes those who had worked in a business of less than 5 people with no income tax levies, also unpaid people who help in a household business not registered for income tax or VAT.

INITIAL VARIABLE VALUES	UNIT	VALUE
Informal Employment	Millions	1.3137
Formal Employment	Millions	9.8500
Unemployment	Millions	3.1663

Table 10: Labour Market Initial Stock Values (SAIRR, 2012)

The Total Employment converter was the sum of the informal employment stock and the formal employment stock, however, a switch was included with a condition statement that provided the user with an option to include/exclude the informal sector in the calculations. Another switch provided the option to use employment data based on an S-curve model or endogenously calculated employment data (aggregated for all the economic sectors). Figure 16 shows the typical structure that was set up to endogenously calculate employment for each of the sectors (Mining and Quarrying, MQ, in this example):

- The historical employment data converter was divided by the historical GDP converter to get an indication of the labour intensity over time.
- The future labour intensity over time was then modeled using an S-curve.
- To obtain the future employment value for the sector, the GDP stock was multiplied by the labour intensity converter.

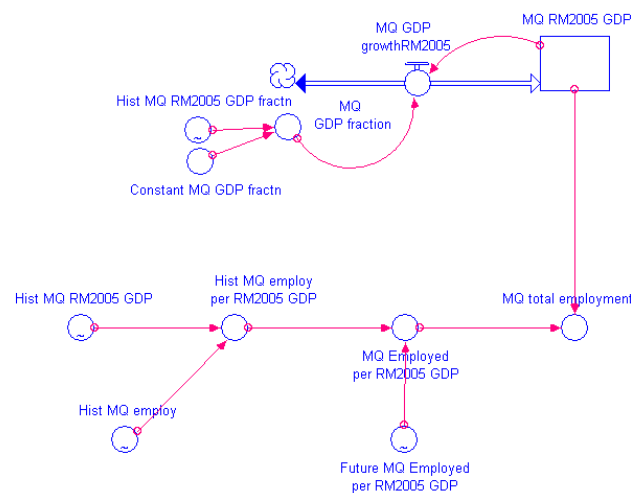


Figure 16: Calculation of the Total Employment (Mining and Quarrying Sector)

For the formal sector stock (not aggregated from the individual sectors), historical data was plotted until 2007 after which the future formal employment growth was modeled using a logistic S-curve function. The same process was followed for unemployment stock.

3.3.2.3 DEPENDENCY RATIOS (DM)

There were two ways in which dependency ratios (DR) were calculated and both methods were included in the simulation for benchmarking and comparison purposes:

1. The Institute for Futures Research (IFR) used the entire economically active group 15-64 years and calculated the ratio of population less than 15 and greater than 64 that were dependent per 100 people in the 15-64 age group.
- 2.

$$DR_{IFR} = \frac{(Population_{<15} + Population_{>64})}{(Population_{15-64})} \times 100$$

3. The South African Institute of Race Relations (SAIRR) used Stats SA data and calculated the dependency ratio of all categories not being paid that were dependent on the employed paid work sector.

$$DR_{SAIRR} = \frac{(Population_{HH \text{ Sector}})}{(Population_{employed})} \times 100$$

The household (HH) sector was calculated as:

$$HH \text{ Sector} = Population - Total \text{ Employed}$$

The model calculations are compared against both the IFR and SAIRR values. For greater sensitivity analysis, a switch was built into the model to investigate the impact of including the unemployed 15-64 dependents. In addition to dependency ratios, the old age and child dependency ratios were also calculated through the following equations:

$$DR_{OLD \text{ AGE}} = \frac{(Population_{>64})}{(Population_{employed \ 15-64})} \times 100$$

$$DR_{CHILD \text{ DEP}} = \frac{(Population_{<15})}{(Population_{employed \ 15-64})} \times 100$$

3.3.2.4 ECONOMIC SECTORS (DM)

In these structures, only the economic sector GDP was modeled as a stock. The model structure developed for each of the economic sectors (ES) was exactly the same so only one structure has been illustrated – Figure 17 (agricultural sector). Simulation algorithms were developed to compute future trends in employment, electricity consumption and wages as a function of changes in GDP (expressed in constant 2005 Rands). The following generic equations were used where *Par* is the parameter of either:

- Electricity (GWh), or
- Wages (Rands), or
- Employment (Numbers).

$$\text{If } time < 2008, (Par \text{ per } GDP)_{ES} = \left(\frac{Par_{Hist}}{GDP_{Hist}} \right)_{ES}$$

$$\text{Else } (Par \text{ per } GDP)_{ES} = \left(\frac{Par_{Future}}{GDP_{Future}} \right)_{ES}$$

Future parameters (expressed as fractions of GDP) were modelled using logistic S-curve equations (to represent best fit through empirical data). Thereafter, the new future values for electricity, wages and electricity were calculated by multiplying $(Par \text{ per } GDP)_{ES}$ with the future GDP growth values to allow a dynamic causal link of these variables to user defined GDP growth rate projections (as explained in Section 3.3.4).

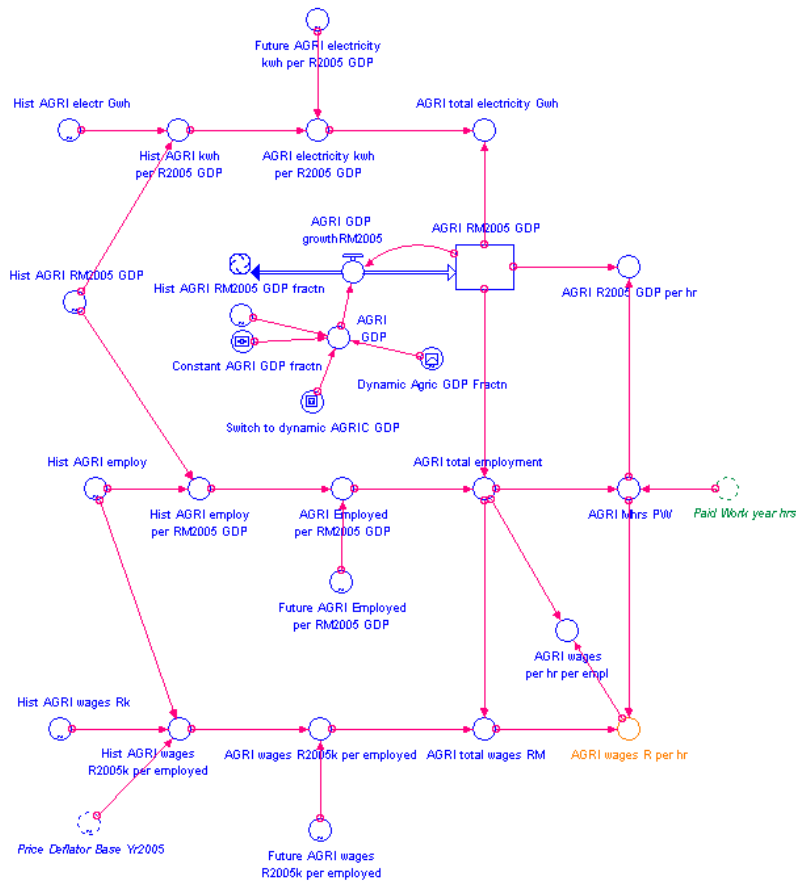


Figure 17: Economic sector structure (Agriculture)

3.3.2.5 HOUSEHOLD INCOME (DM)

Household (HH) disposable income was calculated by deducting taxes from the household current income (also referred to as gross income) while household savings was calculated by deducting the household final consumption expenditure (FCE) from the household disposable income. All units were in constant 2005 Rands (millions).

The calculations for this part of the model are set up as follows (Figure 18):

- The historical HH current income converter was divided by the GDP stock to provide an indication of the historical HH current income per GDP.
- The future HH current income per GDP was kept at a constant 0.78.

- To calculate the future HH current income, the ratio of future HH current income per GDP converter was multiplied by the modelled GDP stock.
- The historical HH taxes on income and wealth converter was divided by HH current income to yield historical HH taxes per HH current income.
- The future HH taxes per HH current income was kept at a constant 0.1.
- The HH final consumption expenditure (FCE) stock was calculated as follows – Equation 9.

$$FCE_{HH} = FCE_{HH}(t - dt) + (FCE_{HH} \text{ growth rate}) \times dt \quad \text{Equation 9}$$

- The HH final consumption expenditure (FCE) stock was divided by the GDP stock to obtain a historical HH FCE per GDP.
- The future HH FCE per GDP was kept constant at 0.68.

Constant values of future HH current income per GDP, future HH taxes per HH current income and future HH FCE per GDP were used since it was difficult to establish what the dynamics of future growth paths would be, within the limitations of this project.

The HH FCE, HH current income and HH disposable income were used to calculate the HH savings per decile capita, explained after the Gini fraction calculations in the next section.

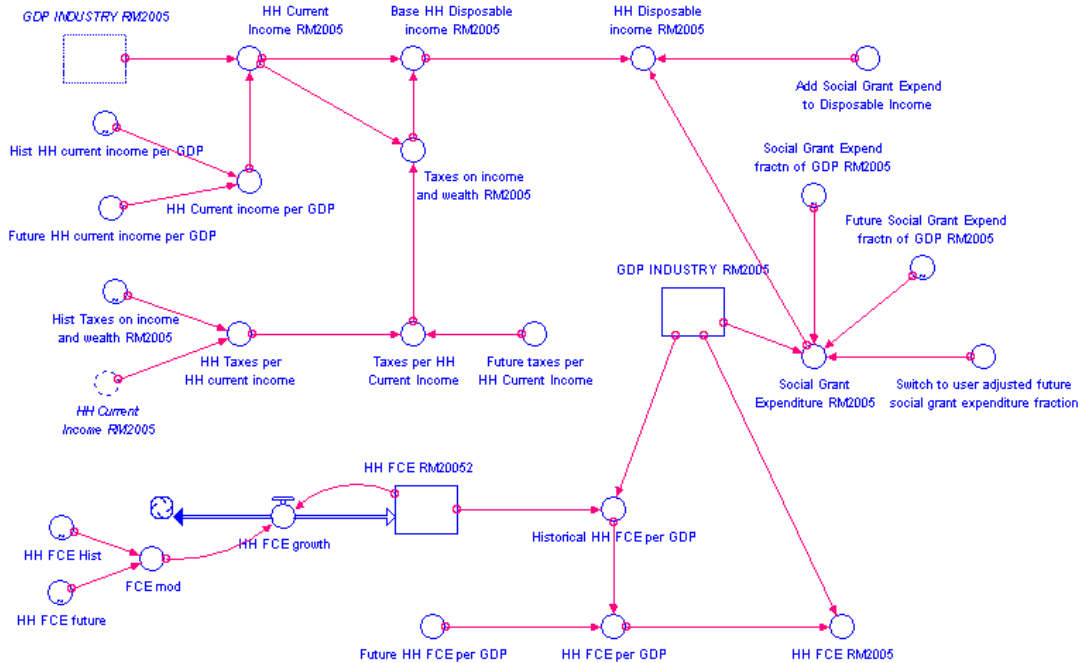


Figure 18: Household Disposable Income and Savings

3.3.2.6 GINI COEFFICIENT AND RESIDENTIAL ELECTRICITY CONSUMPTION (DM)

The model built in structural causality that allowed sensitivity analysis by calculating the residential electricity consumption when the Gini coefficient is varied (Figure 19).

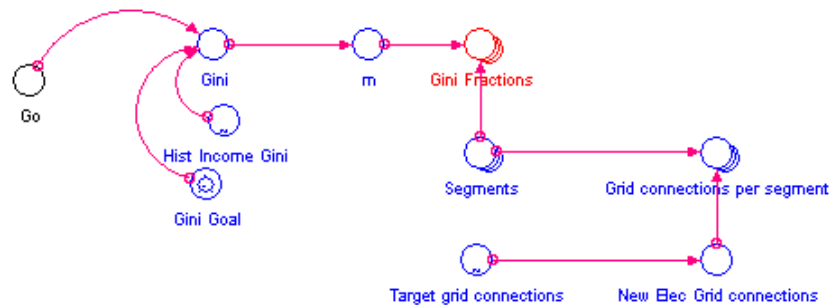


Figure 19: Structure for Gini Fraction

To allow for this, a mathematical representation of the Gini coefficient is required. The first step was to find the parameters for the Gini variable that could describe a smooth transition with variable rates of change as required for sensitivity analysis of the calibrated Gini trend into the future for data after 2010. This was carried out through Equation 10:

$$Gini = G_0 \times \left(U_0 + \frac{U_1}{1 + \exp[-c(t - t_0)]} \right) \quad \text{Equation 10}$$

Where: G_0 = 0.75 (initial value)
 U_0 = 0.68
 t_0 = 2040
 U_1 = $Gini_{Goal} - 0.68$
 c = (-0.10)

It was apparent that since South Africa's Gini coefficient did not follow the classic Lorenz curve (Equation 11), it was necessary to develop an exponential growth curve (Equation 13) that could be used in combination with the Lorenz curve. The resolution of StatsSA data only allows for a rough numerical integration to calculate the Gini coefficient. It is evident from the Figure 20 below that using a pure Lorenz curve does not fit the shape of the data well and will result in large interpretation errors.

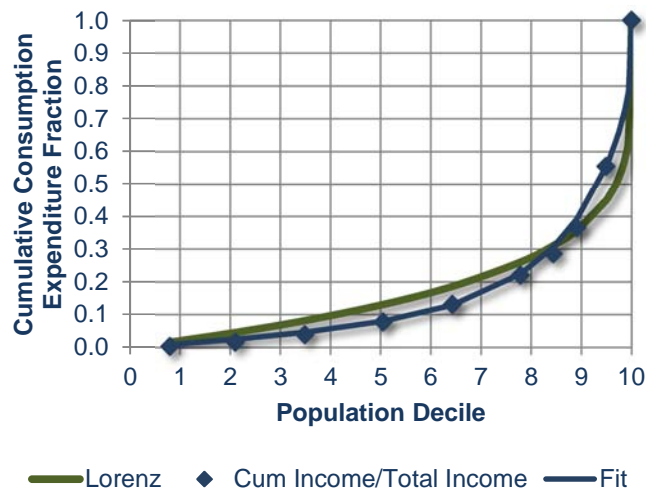


Figure 20: Fitted Data Compared to a Lorenz Curve

Preliminary calculations shows an error of -1.79 for the modified equation while an error of -7.68 (higher than the actual) was evident for the Lorenz equation (lower than the actual). From previous research completed by Nel (2011), the cumulative distribution $k(x)$ was expressed as the linear combination of the Lorenz and the exponential functions (Equation 13).

$$L(x) = 1 - \left(1 - \frac{x}{10}\right)^{\left(1 - \frac{1}{m}\right)} \quad \text{Equation 11}$$

$$g(x) = \frac{\left(e^{\frac{-kx}{10}} - 1\right)}{\left(e^{-k} - 1\right)} \quad \text{Equation 12}$$

$$k(x) = (C)g(x) + (1 - C)L(x) \quad \text{Equation 13}$$

Equation 13 was fitted to the Stats SA 2005/6 income and expenditure data with values:

$$C = 0.54735$$

$$m = 1.2491$$

$$k = 4.3283$$

The Lorenz-curve parameter m was then used to calibrate variation in Gini distributions from this base, deriving the function in the form shown in Equation 14:

$$m = 5.1554 \times 10^2 G^4 - 1.24196 \times 10^3 G^3 + 1.1258 \times 10^3 G^2 - 4.5791 \times 10^2 G + 7.2139 \times 10^1$$

Equation 14

For $0.40 \leq G \leq 0.75$

The Gini fractions were then calculated using a *Segment(Fraction)* arrayed variable (Equation 16) and the m value in Equation 14. The income distribution is calculated at the resolution of population fractions and cast into the arrayed variable, Segments, for further use. A dummy variable, *Segment(Fraction)* (Equation 16) was generated as a reference to the income fraction values with values calculated from Equation 15 (substituting the coefficients into Equation 13).

$$\text{Gini fractions} = 0.54735 \times \frac{\left(\exp(4.3283 \times \text{Segment}[\text{Fraction}]) - 1\right)}{\left(\exp(4.3283) - 1\right)} + (1 - 0.54735) \times \left(1 - \left((1 - \text{segment}[\text{fraction}])^{(1 - 1/m)}\right)\right) \quad \text{Equation 15}$$

The *Segment(Fraction)_i* variable has been defined as follows (Equation 16), where: i is an integer from 1 to 10 and represents each income decile:

$$\text{Segment}(\text{fraction})_i = \frac{i}{10} \quad \text{Equation 16}$$

The income per household decile was calculated as the difference between successive Gini fractions (the variable representing income distribution fractions). In using the Gini fractions, HH disposable income per decile was calculated and divided by the average number of people per household to work out the HH disposable income per capita per decile. By removing the calculated HH FCE per capita per decile, the HH savings per capita per decile was computed. Figure 21 shows the model structure that was developed for calculating the HH disposable income and savings per capita per decile.

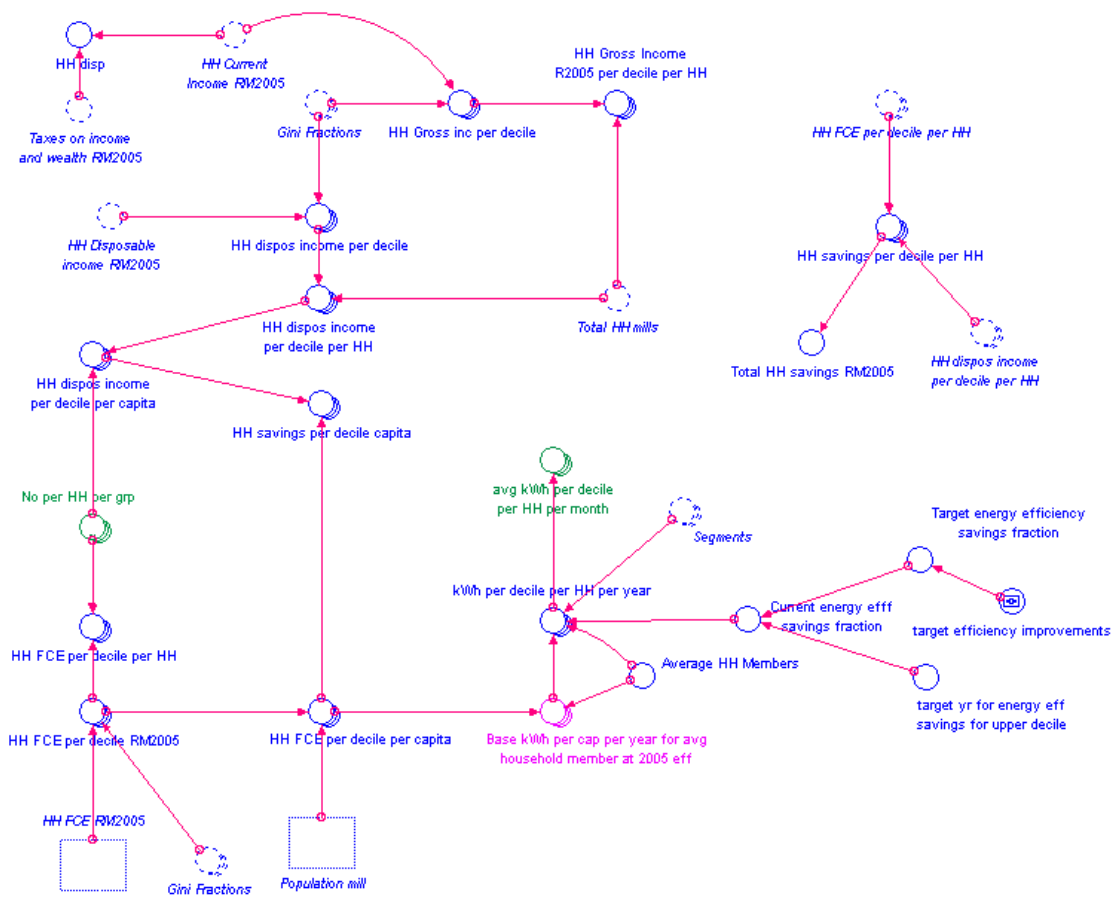


Figure 21: Household Income, Gini Coefficient and Residential Electricity Consumption

An equation was devised based on the causality between HH FCE and residential electricity consumption, before linking the model variables, explained below.

The *Base electricity consumption per cap per year* (Equation 17) for the average household member was calculated as follows before including in the simulation algorithm, with HH FCE

calculated as per capita per decile (Nel, 2011) with an update to the formula through verbal communication and discussion.

The *Average HH members* was kept at a constant of 3.8. StatsSA 2010_11 data shows a linear decline trend in the average number of people per household and if this trend is extrapolated past 2030, it means that the HH numbers would end up being less than 2 people per HH, eventually becoming negative, which does not seem plausible with an increasing population and general socio-dynamics within societies. This makes it difficult to use as a reference for calculation methodologies for the simulator since the simulator run period is until 2035, hence the average household member value of 3.8 used in Equation 17.

$$\text{Base electricity consumption per cap per year} = \frac{\text{Base electricity consumption per year}}{\text{Average HH members}} \quad \text{Equation 17}$$

$$\text{Base electricity consumption per year} = U_0 + \frac{U_1}{1 + \exp[-c(v - v_0)]} \quad \text{Equation 18}$$

Where:

U_0	=	-14023.9
U_1	=	14572.9 + 14023.9
v_0	=	298.77
v	=	HH FCE[fraction] × Average HH members
c	=	5.17×10^{-6}

The *Electricity consumption per decile per HH per year* (Equation 19) is then calculated using the *Base electricity consumption per cap per year* (Equation 17) and the energy efficiency savings (Equation 20).

$$\begin{aligned} &\text{Electricity consumption per decile per HH per year} = \\ &\text{Base electricity consumption per capita per year[fraction]} \times \text{Average HH members} \times \\ &(1 - \text{Current energy efficiency savings fraction} \times \text{segments[fraction]}/10) \quad \text{Equation 19} \end{aligned}$$

Efficiency savings is modelled for different trend scenarios using S-curves with different c values. The *Current energy efficiency savings fraction* (Equation 20) was calculated using a c value of 0.5. The reason behind this particular value for c (which determines whether the curve has a step change or smooth transition) can be illustrated by plotting a range of values

between 0.1 and 1 in Figure 21. In implementing policies, it takes time to gain traction but the transition needs to be done as fast as possible. When the range of c values were plotted, $c=0.5$ provided a plausible balance for rational policy implementation.

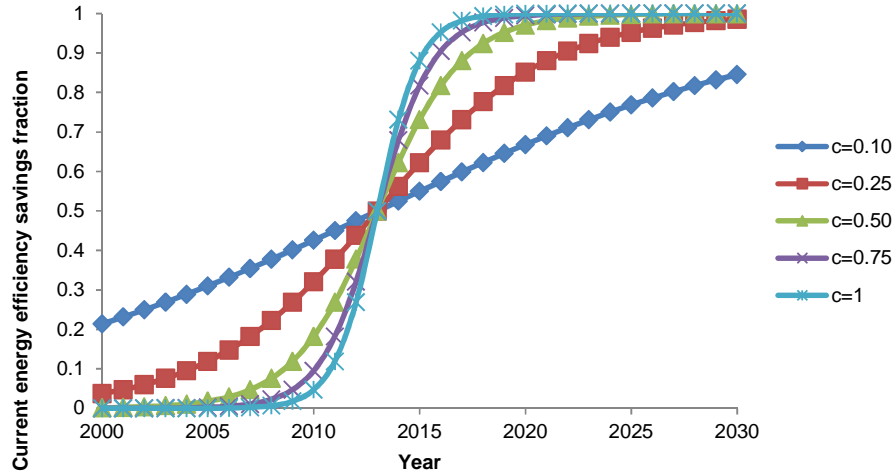


Figure 22: Current energy efficiency savings fraction for selected C values

Current energy efficiency savings fraction

$$= \frac{\text{Target energy efficiency savings fraction}}{\left(1 + \exp\left(-0.5 \times \left(\text{Time} - \left(2006 + \frac{(\text{Target year for energy efficiency savings} - 2006)}{2}\right)\right)\right)\right)} \quad \text{Equation 20}$$

Where:

Target year for energy efficiency savings = 2020

And:

Target energy efficiency savings fraction = If time
< 2007 then 0 else *Target efficiency improvements*

The *Target efficiency improvements* is a switch that can be activated by the model user and is set at a default value of zero (not active).

3.3.2.7 RESIDENTIAL ELECTRICITY COST PER DECILE (DM)

For each of the four Eskom tariff blocks, stocks were created that allowed the tariffs to be changed through changing the tariff block bi-flows. The residential cost of electricity in

Rands per decile for households was calculated after setting up the tariff structures using Eskom block tariffs, as follows (Equation 21):

$$(Eskom\ Tariff\ Block_i)(t) = (Eskom\ Tariff\ Block_i)(t - dt) + (Tariff\ Block\ inflow\ rate_i) \times dt \quad \text{Equation 21}$$

Where *Eskom Tariff Block_i* is the Eskom block tariff (Rands per kWh and *i* is a number from 1 to 4). All initial stock values are R0.70 and start from year 1994 (Ramokgopa, 2008).

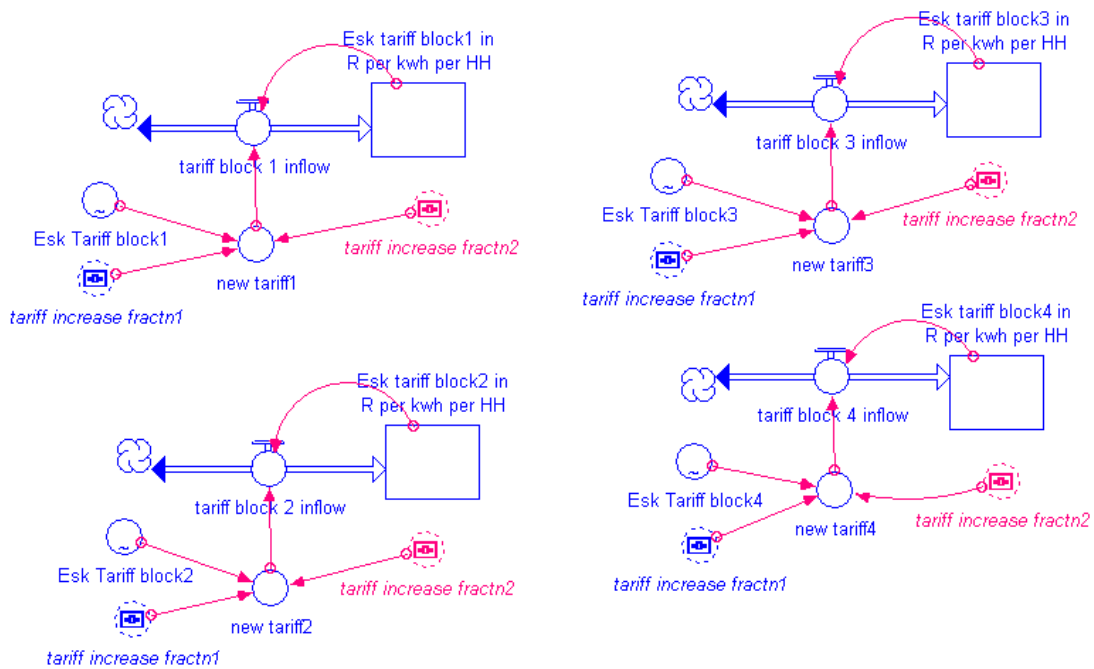


Figure 23: Stock Flow Structures for the Eskom Block tariffs

The *Residential electricity cost per decile per HH per month* (Equation 22) was then calculated as follows (Figure 24) where *i* goes from 1 to 4:

$$Residential\ electricity\ cost\ per\ decile\ per\ HH\ per\ month = \sum_1^4((Eskom\ Tariff\ Block_i)(t) \times Block_i[Fraction]) \quad \text{Equation 22}$$

The cost of electricity per household per month for each decile is based on the average household income for the decile based on income distribution as calculated in Section 3.3.8.

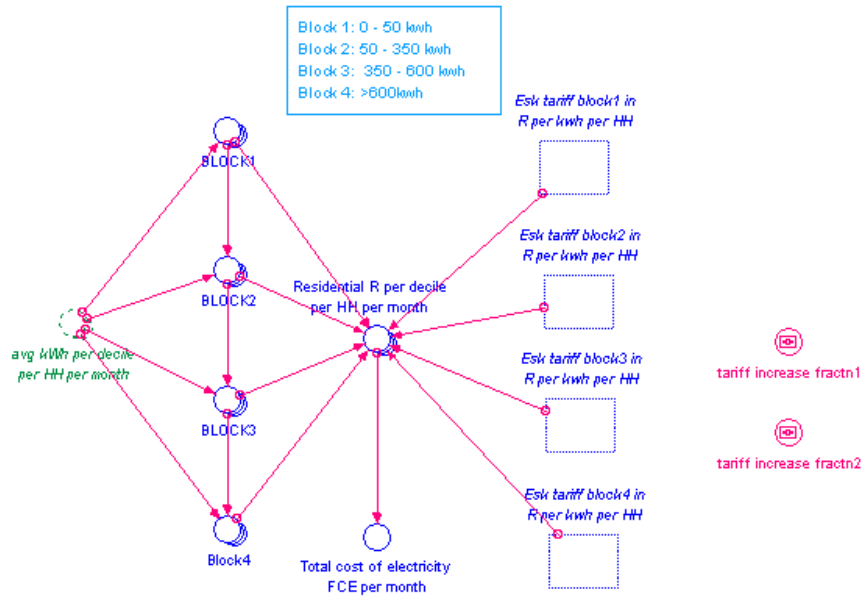


Figure 24: Calculation of Residential Electricity Cost

The logic and tariff volumes (kWh) for each of the blocks are explained in Table 11:

BLOCK	TARIFF QUANTITY(kWh)	MODEL LOGIC
1	0 – 50	If average electricity per decile per HH per month[fraction] >50 then 50 else average electricity per decile per HH per month[fraction]
2	50 – 350	If Block1[fraction] =50 then if average electricity per decile per HH per month[fraction] >350 then 300 else average electricity per decile per HH per month[fraction] -50 else 0
3	350 – 600	If Block2[fraction] =300 then if average electricity per decile per HH per month[fraction] >600 then 250 else average electricity per decile per HH per month[fraction] -350 else 0
4	> 600	If Block3[fraction] =250 then average electricity per decile per HH per month[fraction] -600 else 0

Table 11: Block Tariff Data used in Tariff Stocks

For purposes of user engagement to generate scenarios with the model, work was done on creating an interface for non-modellers to understand and engage with the model. Snapshots

of the interface are included in the next section. The interface snapshots show the variables that could be dynamically changed through levers or sliders or push buttons.

3.4 MODEL INTERFACE (INCLUDED AS A SEPARATE FILE FOR REVIEW)

3.4.1 SIMULATING INCOME DISTRIBUTION (SID) HOMEPAGE

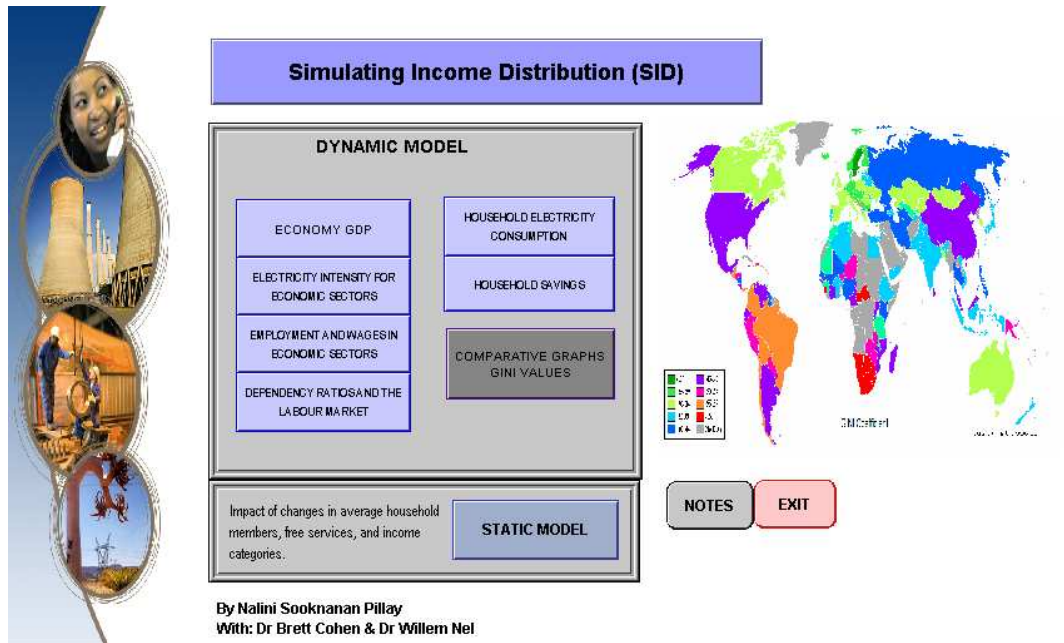


Figure 25: Homepage Interface: Simulating Income Distribution (SID)

The homepage allows navigation to the Static Model dynamics, the Dynamic Model dynamics and allows viewing comparative Gini coefficient values from different sources.

3.4.2 STATIC MODEL

The Static model allows the user to change various income categories and household sizes to endogenously calculate a respective Gini coefficient.

MODEL	USER CONTROLS
Static Model	<ul style="list-style-type: none"> Change in average household members for deciles 1 to 10 through sliders. Push button activation of social grants component of income category. Push button activation of free services and when activated, change in subsidies for free water, electricity and sanitation through knob controls. Push button activation to include or exclude various income categories in addition to income from wages/salaries. A numeric display indicates the calculated Gini coefficient based on the users selection of scenarios. The Gini coefficient endogenously calculated value is also visible on the status indicator which has the option of 3 ranges which correspond to different colours, in this case: <p style="text-align: center;">Gini Indicator Ranges</p> <p style="text-align: center;">Good: 0.10 - 0.49</p> <p style="text-align: center;">Bad: 0.50 - 0.63</p> Unacceptable: >0.64

Table 12: Summary of the Static Model Interface Developed using Stella

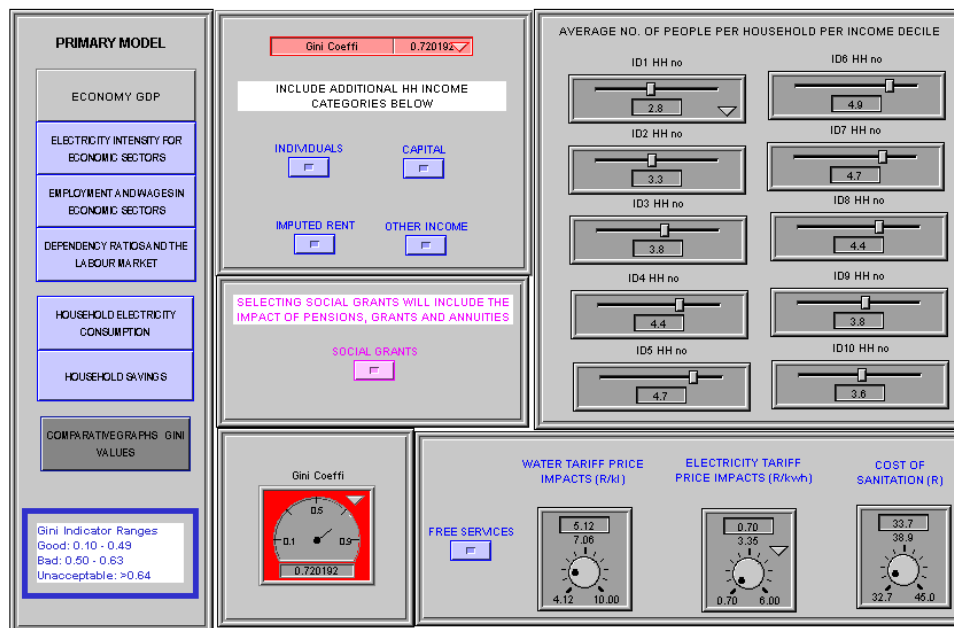


Figure 26: Static Model Interface

3.4.3 THE DYNAMIC MODEL INTERFACES: ECONOMY, GDP

The Dynamic model includes interfaces that deals with the economic sector dynamics, electricity intensity calculations based on changing GDP growth, employment and wage calculations, dependency ratios and the labour market, as well as residential electricity consumption dynamics with changing Gini coefficient.

MODEL	USER CONTROLS
Dynamic Model: Economy GDP	<p>The historical GDP trends (aggregated from the different economic sectors) were included in the GDP structure up until 2010, after which the user has an option of:</p> <ul style="list-style-type: none"> choosing a slider to vary a constant rate fraction at which the GDP can increase from 2011 until 2035 or Activating the dynamics GDP push button and then changing the annual fraction increase of GDP from 2011 until 2035 though a graphical user interfaces (GUI). <p>The bottom left includes sliders for a few economic sectors to observe the sensitivity of constant GDP fraction changes in each economic sector to the overall GDP.</p> <p>The graphs trend GDP per capita, GDP per paid work hour and GDP per employed person.</p>

Table 13: Summary of the Dynamic Model Interface- Economy, GDP

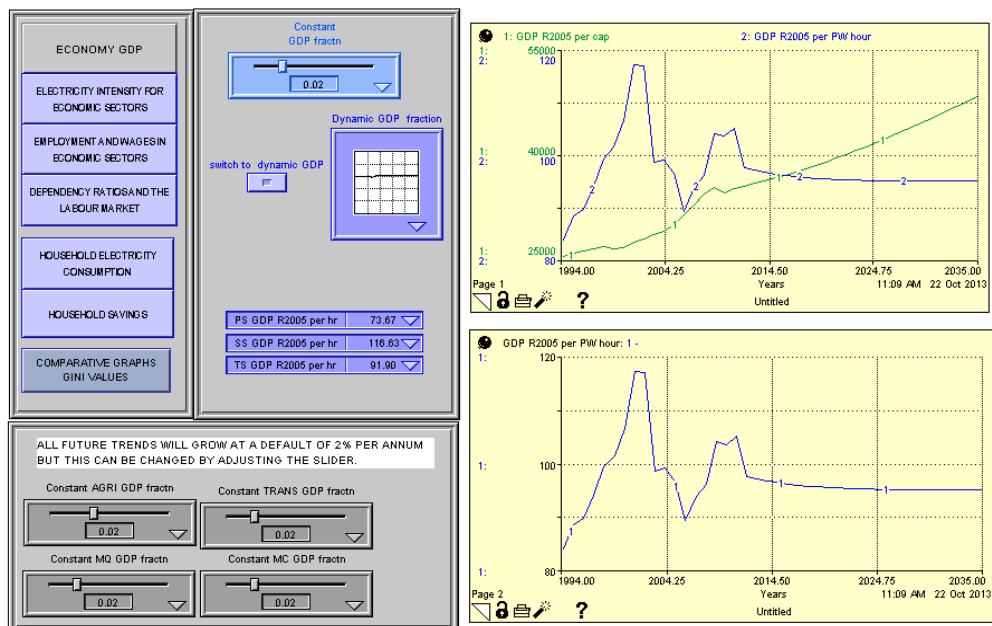


Figure 27: Dynamic Model Interface - Economy, GDP

3.4.4 THE DYNAMIC MODEL INTERFACES: ELECTRICITY INTENSITY

MODEL	USER CONTROLS
Dynamic Model: Electricity Intensity for the economic Sectors	Interface just provides visuals of the electricity per GDP for each of the economic sectors and the overall economy. It also has comparative tables that allow changes in electricity intensity to be observed for different values of GDP.

Table 14: Summary of the Dynamic Model Interface - Electricity Intensity

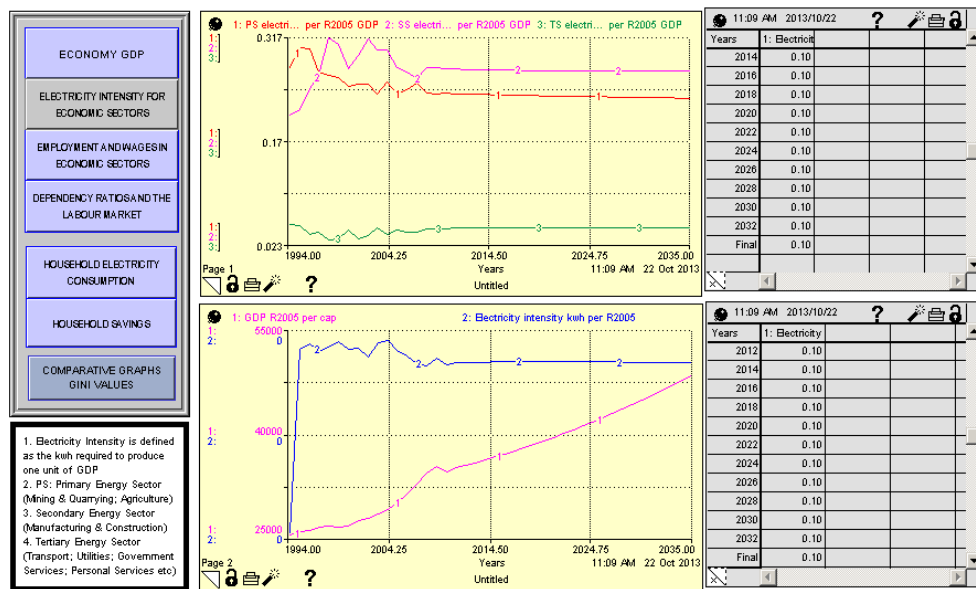


Figure 28: Dynamic Model Interface- Electricity Intensity

3.4.5 THE DYNAMIC MODEL INTERFACES: EMPLOYMENT AND WAGES

MODEL	USER CONTROLS
Dynamic Model; Employment and wages in economic sectors	<ul style="list-style-type: none"> • Graphs are drawn to display the trends of total employment per economic sector over time for different GDP growth rates. • Wages per employed person provides an indication of the average within the primary, secondary and tertiary sectors. • Comparative tables are used to observe the change in overall employment based on different GDP growth rates.

Table 15: Summary of the Dynamic Model Interface - Employment and Wages

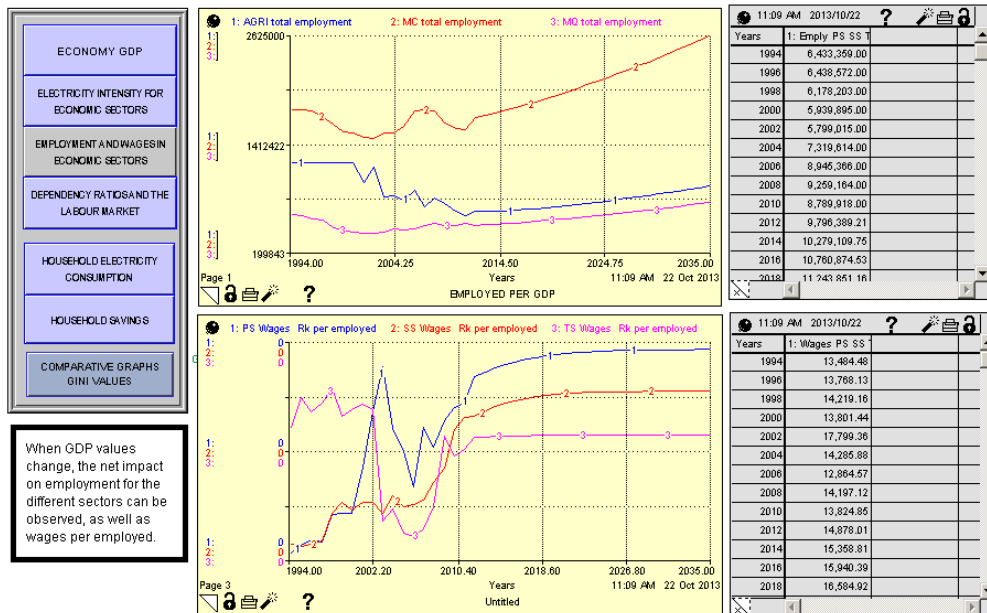


Figure 29: Dynamic Model Interface- Employment and Wages

3.4.6 THE DYNAMIC MODEL INTERFACES: DEPENDENCY RATIOS

MODEL	USER CONTROLS
Dynamic Model: Dependency ratios and the labour market	<ul style="list-style-type: none"> • A slider allows unemployment to be changed by changing the unemployment fraction of the population. • A push button provides the user with the option to include the unemployed between 15-64 years in the dependency calculations or to leave only the paid work sector between 15 and 64 years as the default working age group. • A push button allows the inclusion of the informal sector in the dependency calculations. • Graphs plot the dependency of the unemployed on the working 15-64 years age group as well as the dependency of the old age group (>64 years) on the paid work sector; as well as the child dependency (<15 years).

Table 16: Summary of the Dynamic Model Interface - Dependency Ratios and the Labour Market

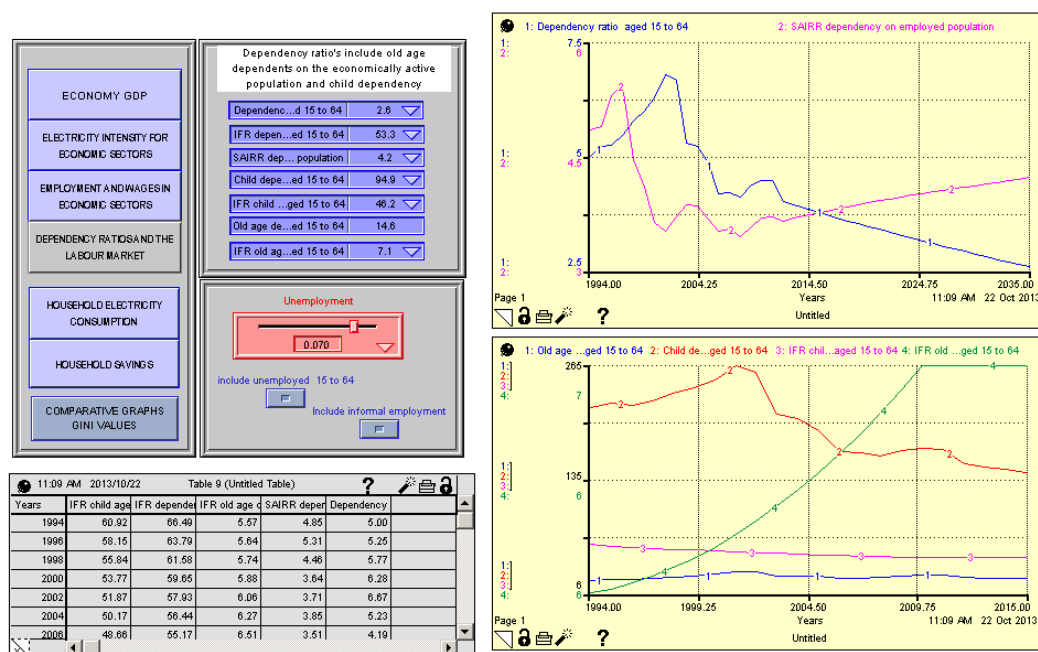


Figure 30: Dynamic Model Interface - Dependency Ratios and the Labour Market

3.4.7 THE DYNAMIC MODEL INTERFACES: HOUSEHOLD ELECTRICITY CONSUMPTION

MODEL	USER CONTROLS
Dynamic Model: Household electricity consumption	<ul style="list-style-type: none"> A knob control with values for Gini coefficient is accessible. The user can change the Gini coefficient from 0.30 to 0.90, with a default value of 0.67. A target efficiency slider is available for changing the electrification rate. Once a Gini coefficient value is chosen, the simulator computes the causally linked residential electricity consumption (overall) as well as within deciles within households.

Table 17: Summary of the Dynamic Model Interface - Household Electricity Consumption

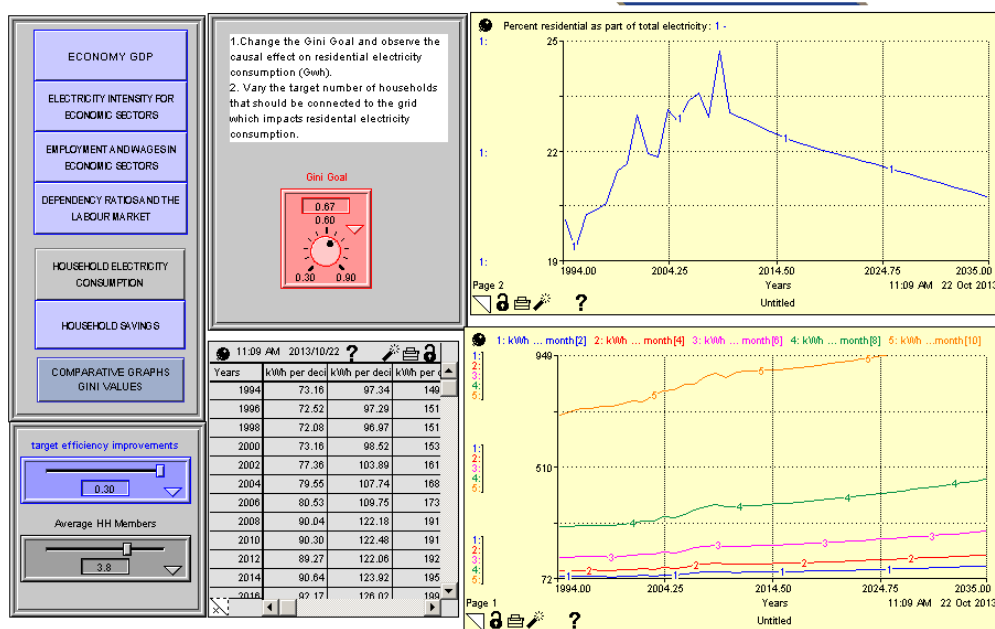


Figure 31: Dynamic Model Interface - Household Electricity Consumption

3.4.8 THE DYNAMIC MODEL INTERFACES: HOUSEHOLD SAVINGS

MODEL	USER CONTROLS
Dynamic Model: Household savings	<ul style="list-style-type: none"> This interface provides graphs of the savings per household with a default annual tariff increase of 8% per year over 5 years and then 7% per year until 2023.

Table 18: Summary of the Dynamic Model Interface - Household Savings

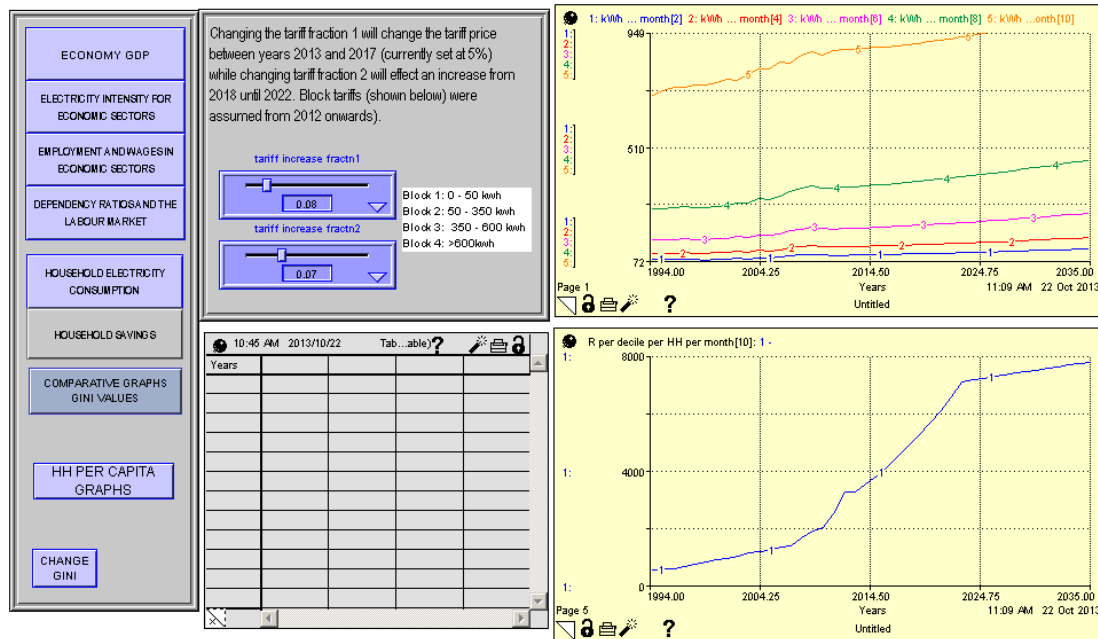


Figure 32: Dynamic Model Interface - Household Savings

3.4.9 COMPARATIVE GRAPHS FOR GINI COEFFICIENT

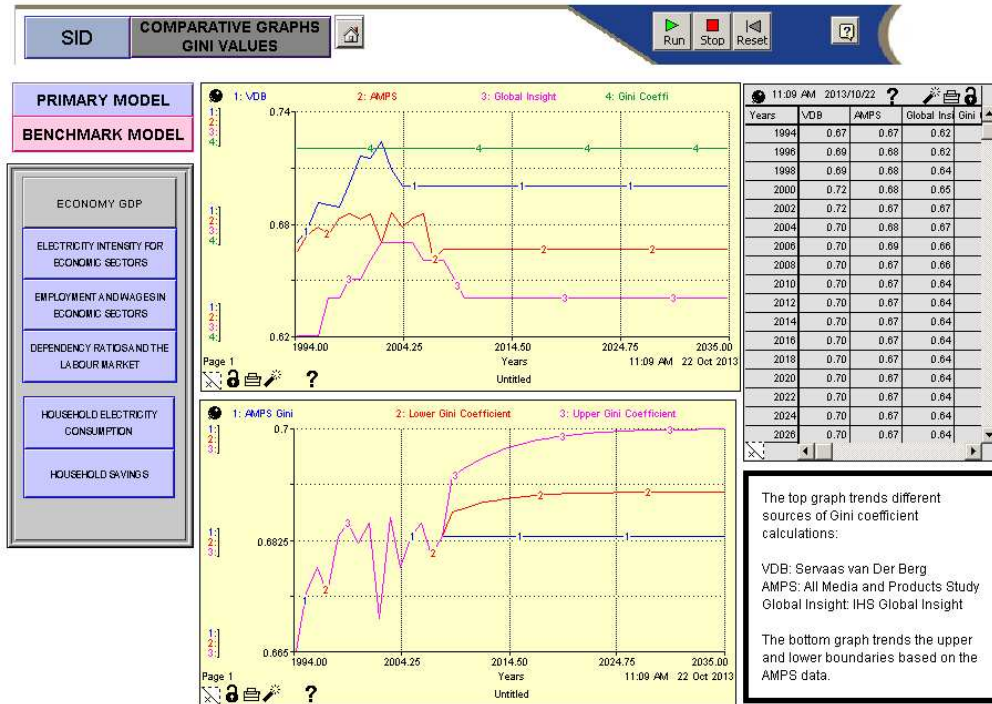


Figure 33: Comparative Graphs Interface

CHAPTER 4: MODEL RESULTS AND DISCUSSION

This chapter presents a summary of the results obtained from running the model. The results include the base runs with no shocks to the existing structure, as well as selected additional scenarios as described below to demonstrate the sensitivity analysis. In reading the results, however, it is critical to note that there are numerous other scenarios that could be run. The runs presented here are selected to demonstrate the operation of the models and their potential to provide insights into the system performance.

The results that are explained in this chapter were obtained from the following models, summarised in Table 19:

STATIC MODEL (SM)	DYNAMIC MODEL (DM)
4.1.1 Changes in average HH members and impact on Gini coefficient.	4.2.1 GDP per capita and GDP per paid work hour.
4.1.2 Changes in HH income categories and impact on Gini coefficient.	4.2.2 Sensitivity of dependency ratios for labour market changes.
4.1.3 Impact of free services (water, electricity, sanitation) on Gini coefficient.	4.2.3 Causality between Gini coefficient and residential electricity consumption.
	4.2.4 Residential consumption per HH per decile per month.
	4.2.5 Residential HH savings per month per decile.

Table 19: Summary of Model Results

4.1 STATIC MODEL

4.1.1 CHANGES IN AVERAGE HOUSEHOLD MEMBERS AND IMPACT ON GINI COEFFICIENT (SM)

The Stats SA 2005/6 average household members per decile are indicated in Table 20 (base case). This table also includes 3 scenarios where the average household members are changed and then Gini coefficient endogenously calculated (the calculation was also done for the base case). Scenario 1 considers a decrease in average household members for the

lower income deciles, while Scenarios 2 and 3 consider a decrease for the upper deciles. The incomes that were included for the baseline calculations of Gini is income from wages, individuals, capital, imputed rent, other income and social grants. The reason for doing the sensitivity analysis was to observe if there is causality between household structure and income distribution and if so, what the sensitivity could be.

It is important to note that the average HH members chosen for the scenario analysis (Table 20) have not been linked to equivalence scales which take into account that households have different sizes and compositions and may enjoy economies of scale when sharing resources among HH members (in other words, households with non-working adults would include income only from non-work sources such as government subsidies while households with more than two working adults may generate a larger relative income).

Household survey data from 1996 to 2006 indicate that the average size of the South African HH has declined from 4.4 persons to 3.2 (Van Zyl, Cross, & O' Donovan, 2008). If this trend is extrapolated past 2030, it means that the HH numbers will become negative, less than one person per HH which does not seem plausible with an increasing population and general socio-dynamics within societies. Two-person households were considered as potentially viable if the number of childless couples increases (increase in infertility) and if life expectancy increases (resulting in a greater incidence of elderly two-person households).

DECILE HH No.	1	2	3	4	5	6	7	8	9	10	Gini Coeff. (A) ¹⁰	Gini Coeff. (B) ¹⁰
Base Case	2.8	3.3	3.8	4.4	4.7	4.9	4.6	4.4	3.8	3.6	0.67	0.62
Scenario 1	2.0 ¹¹	2.0	2.0	2.0	4.7	4.9	4.6	4.4	3.8	3.6	0.61	0.55
Scenario 2	2.8	3.3	3.8	4.4	4.7	4.9	2.0	2.0	2.0	2.0	0.71	0.68
Scenario 3	2.8	3.3	3.8	4.4	4.7	4.9	3.0	3.0	3.0	3.0	0.68	0.64

Table 20: Change in Average Household Numbers (StatsSA 2005/6) ^{10,11}

¹⁰ The Gini coefficient (A) includes social grants while Gini coefficient (B) includes social grants and free services.

¹¹ The numbers in red are decreases in average HH members for income groups

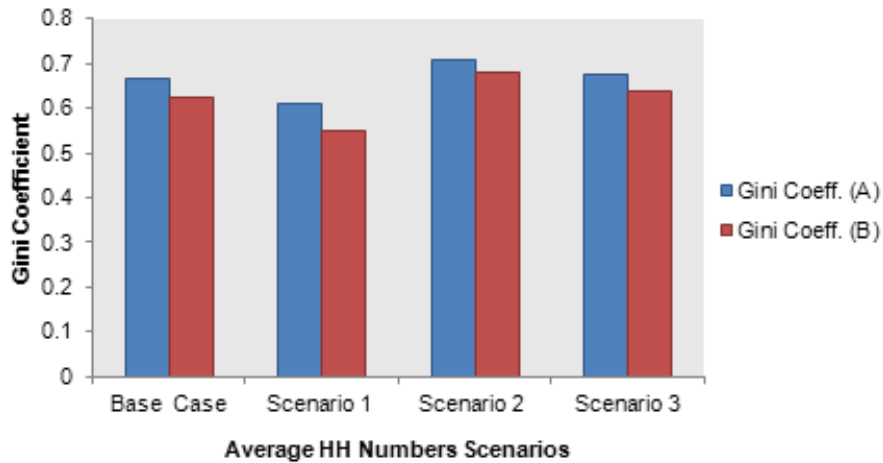


Figure 34: Gini Coefficient for Varying HH Numbers (StatsSA 2005/6)¹²

The Gini coefficient (A) base case for the average HH size as calculated using the StatsSA 2005/6 data is 0.67. For a constant average HH size of 2 in the first four deciles, there is greater improvement in the Gini index (Gini coefficient of 0.61), compared to the case of an average HH size of 2 for the upper 4 deciles (Gini coefficient of 0.71). Scenarios were generated with and without free services for sensitivity analysis.

The exact drivers that result in the difference in Gini coefficient (by varying the upper and the lower deciles and decreasing them to the same average HH numbers) needs to be researched further although literature indicates that there is higher relative income inequality with a drop in average HH members for the upper deciles compared to the lower deciles indicating that inequality is largely driven by changes in the average number of members in the upper deciles.

4.1.2 CHANGES IN HH INCOME AND IMPACT ON GINI COEFFICIENT (SM)

The pure system response or base case was established by running the simulator and calculating the Gini coefficient for income from wages and salaries only (Gini coefficient of 0.65). Thereafter income from imputed rent, capital and other income was included (Gini coefficient of 0.71), after which social grants were added (Gini coefficient of 0.67) and finally free services (Gini coefficient of 0.65) - Table 21.

¹² The Gini coefficient (A) includes social grants while Gini coefficient (B) includes social grants and free services

Using 2005/6 Stats SA data	Income from wages/salaries	+ Income from imputed rent, capital, other income	+ Social Grants	+ Free Services
Gini Coefficient	0.65	0.71	0.67	0.65

Table 21: Change in Gini coefficient with Changing Income Components (StatsSA 2005/6)

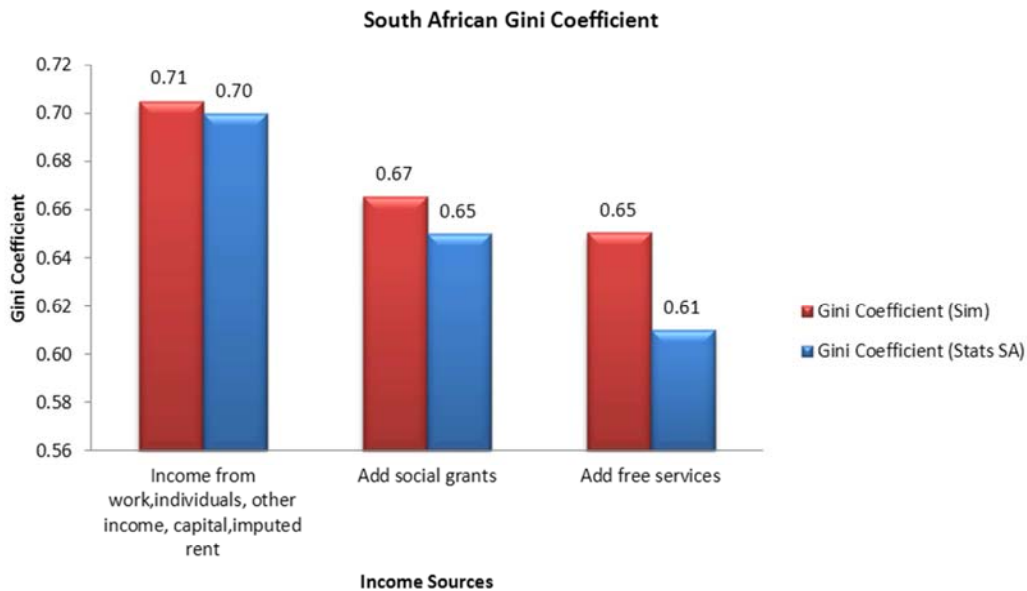


Figure 35: Modelled and Empirical Gini Coefficient values (where Sim refers the simulated results and Stats SA were empirical values) (StatsSA 2005/6)

It is clear that adding income from wages and salaries to income from capital and imputed rent increases the Gini coefficient. This is most likely due to the accumulation of wealth and capital by the higher income deciles which makes the difference between the rich and poor even greater.

Adding social grants (an important source of income for poor households) lowered the Gini coefficient (by 0.04) and adding subsidies further reduced the Gini coefficient by 0.02; but this marginally reduced the gap between the rich and poor. Social grants, overall, do not make a significant impact on the overall Gini coefficient and rather, could improve the income poverty levels and contribute towards social development instead. The one potential unintended consequence with social grants is that it may result in dependency and reduced labour force participation.

A far more accurate sensitivity analysis could be done if equivalence scales were factored into the calculations due to the various sub-categories of social grants (child support grants, disability grants and old age pensions).

4.1.3 IMPACT OF INCLUDING FREE SERVICES DYNAMICS ON GINI COEFFICIENT (SM)

The next set of calculations have been done for the 2005_6 Stats SA data and then changes were made to the tariffs to see what impact this would have had on the endogenously calculated Gini coefficient as part of sensitivity analysis. For the calculations, the following was applied:

- Free basic electricity of 50 kWh was allocated to all deciles.
- Subsidies for water and sanitation were allocated only to deciles 1-4.
- The volume of free water was kept at a 6-12 kl block.

The first set of scenarios for free services deals with changes in the water tariff and the related calculated value for Gini coefficient, while keeping the sanitation cost and electricity tariff constant - Table 22. Thereafter the electricity tariff was changed while keeping the water tariff and sanitation costs constant - Table 23. Lastly, the value assigned to sanitation was increased, while keeping the water and electricity tariffs constant -Table 24.

DECILE	Base Case	25% increase	50% increase	75% increase
Water Tariff (R/kl) For 6-12 kl	5.12	6.40	7.68	8.96
Gini Coefficient	0.6216	0.6201	0.6185	0.6170

Table 22: Impact of Changing Water Tariffs

DECILE	Base Case	25% increase	50% increase	75% increase
Electricity Tariff (R/kwh) for 50 kwh	0.70	0.875	1.05	1.225
Gini Coefficient	0.6216	0.6128	0.6047	0.5963

Table 23: Impact of Changing Electricity Tariffs

DECILE	Base Case	25% increase	50% increase	75% increase
Sanitation (R)	33.72	42.15	50.58	59.01
Gini Coefficient	0.6216	0.6214	0.6213	0.6211

Table 24: Changes in Sanitation Subsidies

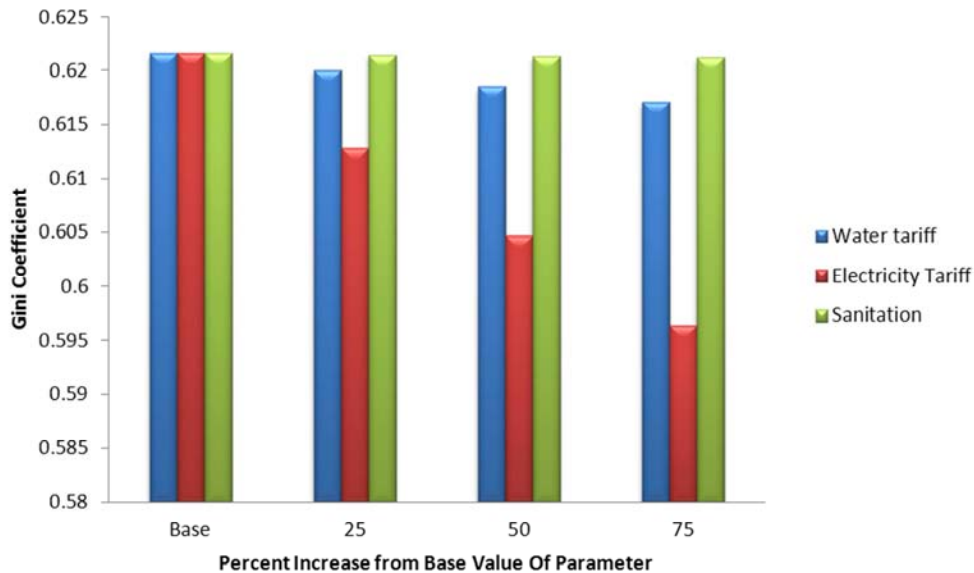


Figure 36: Gini Coefficient with increases in Water Tariff, Electricity Tariff and Sanitation Costs

From the results, Figure 35, varying the sanitation costs has an almost negligible impact on Gini coefficient, while the greatest sensitivity was when the electricity tariff was adjusted. The benefits from the electricity tariff arise when more free electricity is given to the poorer deciles, thus increasing the overall income for these deciles which result in a smaller gap between the lower and the upper deciles and hence a more equal income distribution.

4.2 DYNAMIC MODEL

4.2.1 CHANGES IN GDP EXPRESSED AS GDP PER CAPITA AND GDP PER PAID WORK HOUR (DM)

Generally, GDP is accepted as a measure of a country's economic output. GDP per capita can be viewed as an indication of the country's well-being while GDP per hour can be viewed as a measure of the country's level of productivity.

A 2% GDP growth rate was selected and trends in two alternative economic health indices were determined Figure 37. The low GDP growth rate of 2% was selected for scenario analysis in view of the fact that economists have revised the growth outlook this year to 2%, 0.2 percentage points lower than August 2013 (Reuters, 2013). The trends in the primary, secondary and tertiary economic sectors were modelled to a best fit future trend until 2035. It was also assumed that population growth is S-shaped with a goal of 56.8 million by 2035.

The simulator allows variation but a value of 2% was chosen to illustrate influences:

- GDP per capita, and
- GDP per paid work hour.

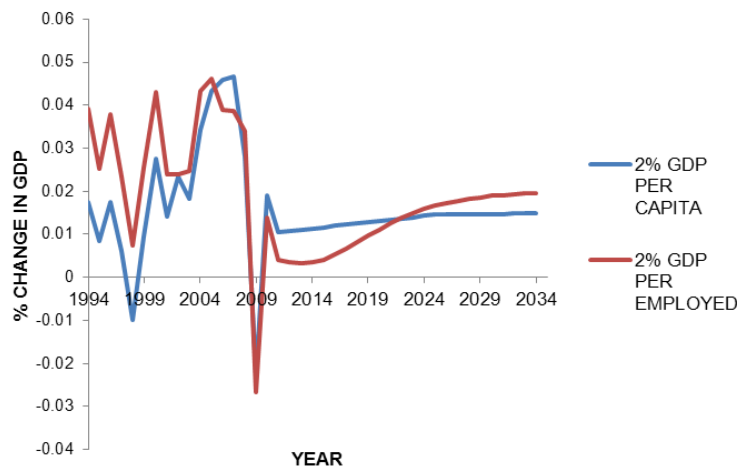


Figure 37: Change in GDP per capita and GDP per paid work (PW) hour as GDP increases (2%)

The graph shows that GDP per capita does not follow the same trend as GDP per paid work hour. Since workers do not work the same hours in every country, differences in productivity are better reflected by the number of hours worked than by the number of people employed.

The hours worked exclude annual leave, sick leave and public holidays. For those countries that display a high GDP per capita and a low GDP per paid work hour, the average annual hours worked per employed person is high. There are, however, other factors that are also of importance including the structure of the economy and capital-to-labour ratios (more achieved per hours with machines). What is interesting is that in the energy intensive primary and secondary sectors, labour productivity reflects on power capacity (Giampietro, Mayumi, & Sorman, 2012).

Calculations using GDP per paid work hour also allow a causal linkage to labour force participation, as opposed to population size, whereas per capita as a statistical indicator, does not factor in demographic changes in society and the social construct of the economy (which tends to result in very optimistic long-term economic trends). External biophysical constraints in the environment will cause trends in economic health indices to stabilize when such constraints become limiting, either on the energy or resource side.

4.2.2 IMPACT OF CHANGE IN GDP ON ELECTRICITY INTENSITY (DM)

Figure 38 illustrates the trends over time for electricity intensity and GDP per capita at a 2% GDP growth rate. Electricity intensity is the total electricity used to support economic and social activity. Although increases in GDP growth rates show an increasing trend in GDP per capita, the electricity intensity has a declining trend which levels off at a much lower relative value.

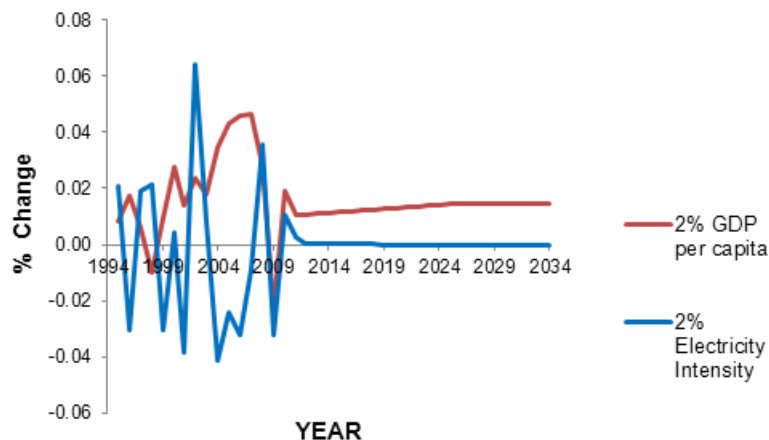


Figure 38: Electricity Intensity and GDP per Capita for 2% GDP growth rate¹³

¹³ Energy intensity is the result of opposing trends in different sectors

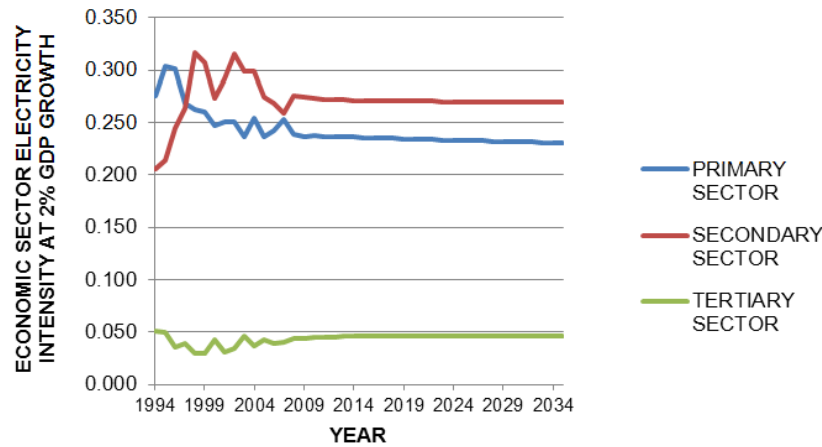


Figure 39: Trends in Electricity Intensity for South Africa with a 2% GDP Growth Rate

Figure 39 shows the relative trends in electricity intensity in South Africa for each of the economic sectors. The trends reflect higher electricity intensity in the primary sector compared to the secondary sector and higher electricity intensity in the secondary sector compared to the tertiary sector.

The stabilization in overall electricity intensity (Figure 38) is due to a dynamic balance between the increasing and decreasing trends in the share of electricity being used by energy-intensive industries in the overall economy and the relative sector sizes which define the ratio of electricity consumption relative to GDP growth (Figure 39). The electricity needed per unit of production changes as the future economic structure and energy demand by industries changes. If there is inadequate electricity for the primary sector, a long-term effect would be a decrease in the size of secondary and tertiary sectors unless growth in these sectors is driven by exports.

4.2.3 IMPACT OF CHANGES IN THE LABOUR MARKET ON DEPENDENCY RATIOS (DM)

Figure 40 illustrates the shift in the demographic profile for South Africa from 1996 to 2011 (Stats SA, 2012). Due to time lag effects, the working age population will change over a 10-15 year period, thus changing the contributions of society towards the economy but also changing the dependency of the unemployed on the paid work sector. If a 15 year time lag is considered, it is expected that the demographic age profile will most likely be similar to Figure 41.

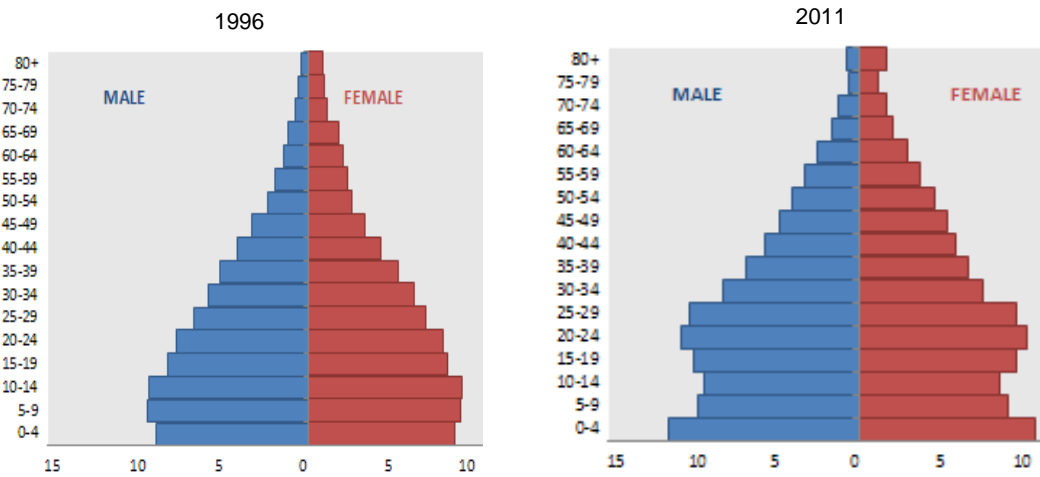


Figure 40 Demographic Age Structure in South Africa (a) Stats SA 1996 Consensus (b) Stats SA 2011

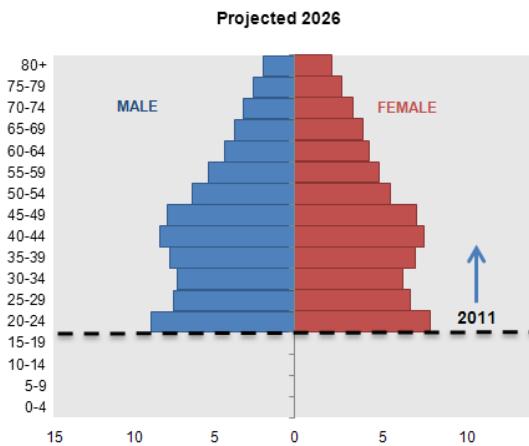


Figure 41: Projected Demographic profile for year 2016 for South Africa (own calculations)

If South Africa does indeed tend towards a profile as indicated by Figure 41, it implies a large working age group in the year 2021 for which employment will be necessary, but for whom employment may not be available. One possible mitigation measure for the current government planners to ensure a successful labour force would be to ensure that the relevant education policies are in place so that a skilled workforce enters the working age group in 15 years. If the majority in the group have high school and tertiary qualifications by the year 2021, there is a greater potential for employment and thus contributions to the economy.

Education also provides beneficial effects for entrepreneurship as drivers to growth:

- Knowledge to start businesses in the more productive sectors of the economy, and
- Availability of a skilled workforce to service the higher labour quality requirements of the more productive sectors.

This also means that in another 15 years (by about year 2036), there will be a greater need for government social expenditure in the form of pensions and possibly healthcare.

To observe the changes in the dependency ratios, calculations were made using employment with (and without) the formal employment sector and then with (and without) the unemployed 15-64 years age group - Figure 42.

From Figure 42, it is clear that the impact of the informal sector on the overall dependency ratio for South Africa is negligible. Some calculations included adding the unemployed in the working age (15-64) to those outside of the employed 15-64 age group.

The consistency in results between demographic age structure and dependency ratio can be understood by looking at the trends in Figure 41 and Figure 42. In 1996, there is a high dependency ratio since there was a smaller working age group, but by 2011, the under 15 years age group matured and moved into the working age category (i.e. evolution of the age structure), thus decreasing the dependency ratio over time.

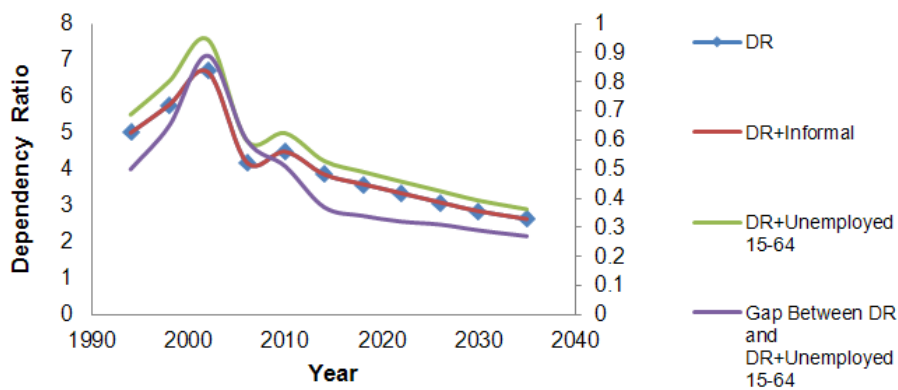
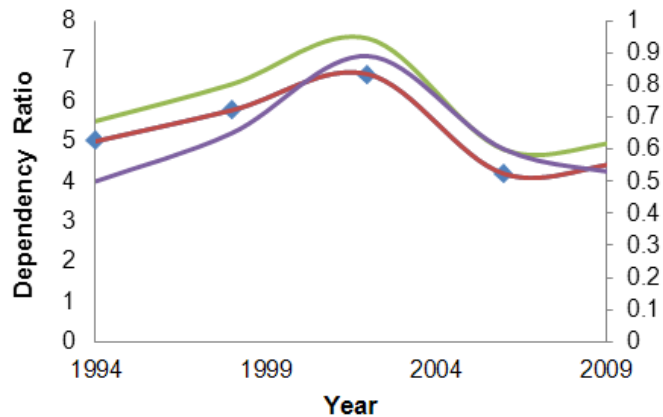


Figure 42: (a) Dependency Ratios with varying Employment Dynamics



(b) Sliced Time period of Dependency Ratios (1994-2008)¹⁴

The different drivers that could affect the demographic age profiles could be as a result of fertility (and population growth), labour market participation, and the economic well-being of a country. An increase in fertility increases the population growth. Population growth increases the ratio of labour-to-capital, of labour-to-land and of land-to-capital (Boulier, 1975). It is also suggested that productivity follows an inverted U-shaped profile where significant productivity decreases prevail after age 50 years. Some causes of the decrease in productivity is explained by age-related cognitive abilities (such as perceptual speed), which decrease with age. Although experience supports productivity, it also levels off at a point, after which, learning appears to slow down with a decrease in memory and reasoning abilities (Prskawetz, Mahlberg, Skirbekk, Freund, & Winkler-Dworak, 2006). The country's economic well-being determines how extensive the welfare system can be. As the number of aged population increases, there will be a greater demand for public spending, however, if this is constrained due to a limited government spending budget, then there could be a requirement for more taxes. If taxes are increased, then the net rate of return on capital decreases, leading to a decrease in capital accumulation, labour productivity and income growth. In turn, this may again require an increase in taxes to maintain tax revenues, thus slowing down economic growth (Brunner, 2007).

All of these factors have a component of time lag behaviour before their effects on income distribution are filtered through. Figure 42 shows the historic Gini coefficient trends over time as calculated by different sources.

¹⁴ The true dependency ratio is the green line (much higher) instead of the red line since this more realistically represents the population dependent on those that are employed (paid work sector) and contributing towards economic growth in the country.

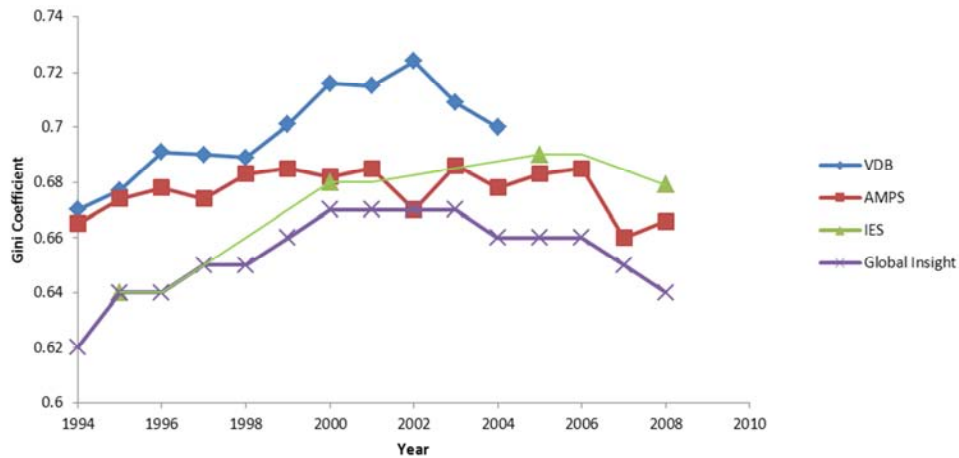


Figure 43: Income Distribution Calculated by Different Sources (VDB: Servaas Van Der Berg; AMPS: All Media and Products Study, IES: Income and Expenditure Survey Stats SA, Global Insight: IHS Global Insight)

When comparing calculated Gini coefficient to the dependency ratio (for the peak income inequality period of 2000-2003) both correspond in trends (Figure 42, Figure 42). In other words, when the Gini coefficient was at its highest, the number of dependents on the paid work sector was the highest since there were far less active workforce participants.

Even within the 15-64 age group, it was expected that if there was a higher number of entry level workforce with relatively lower incomes, the average income in those age groups would have been lower, thus increasing the income inequality measure. Since this project has not been carried out to this resolution, there is no experimental result proving this, just a hypothesis that may also explain the reason for income inequality.

This dynamic is important since it would imply that a larger portion of the government's expenditure would have to be spent on social grants, free services and health care, thus affecting overall income distribution, but also the direction of government's economic growth path.

4.2.4 IMPACT OF CHANGING GINI COEFFICIENT ON RESIDENTIAL ELECTRICITY CONSUMPTION (DM)

One would expect that with an increase in average disposable household income, the average electricity demand for households would causally increase. The relevant question then being, if it changes, how significant is this change and does it fundamentally affect energy and capacity planning.

For the next run to determine the causal relationship between Gini coefficient and residential electricity consumption, GDP growth is assumed to be a constant 2% from 2013 onwards.

Table 25 and Figure 43 display the results of the simulator runs for different values of Gini coefficient. It is clear that the smaller the Gini coefficient value (the more equal the income distribution), the higher the residential electricity consumption, a result that is critical in future energy planning considerations. For a Gini coefficient value of 0.6, by year 2035, there would be approximately a 1.34% increase in residential demand and for a more equal income distribution of 0.3, there is almost a 6.03% increase in residential electricity consumption.

	% CHANGE IN RESIDENTIAL HH CONSUMPTION FOR DIFFERENT GINI COEFFICIENTS, USING A BASE CASE OF RESIDENTIAL ELECTRICITY CONSUMPTION AT A GINI COEFFICIENT OF 0.67					
YEAR	0.30	0.40	0.50	0.60	0.70	0.80
2014	0.99	0.73	0.46	0.19	-0.08	-0.36
2016	1.23	0.91	0.58	0.24	-0.10	-0.45
2018	1.52	1.12	0.71	0.30	-0.13	-0.56
2020	1.86	1.37	0.88	0.36	-0.16	-0.69
2022	2.26	1.68	1.07	0.45	-0.19	-0.85
2024	2.74	2.04	1.31	0.55	-0.24	-1.05
2026	3.28	2.46	1.58	0.66	-0.29	-1.28
2028	3.90	2.95	1.91	0.80	-0.35	-1.55
2030	4.57	3.49	2.27	0.96	-0.42	-1.86
2032	5.29	4.09	2.69	1.14	-0.50	-2.22
2035	6.03	4.73	3.14	1.34	-0.59	-2.62

Table 25: Residential Electricity Consumption as a Function of Gini Coefficient

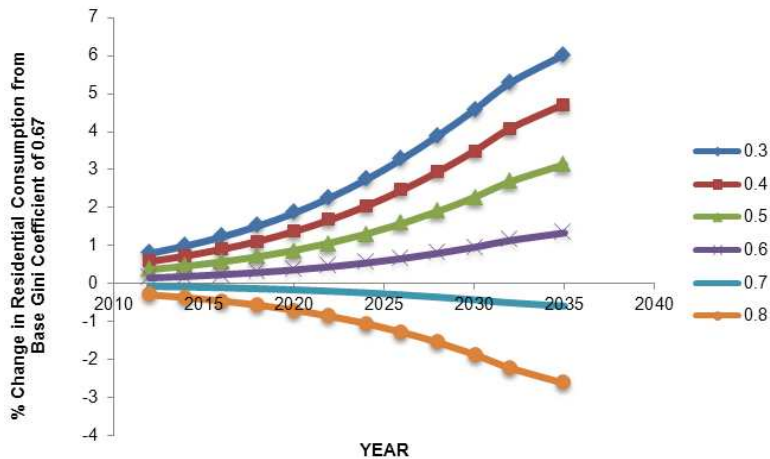


Figure 44: Percent Change in Residential Consumption from a Base Gini Coefficient of 0.67

Based on Figure 42 and depending on the data source, the Gini coefficient for South Africa has hovered between a low of 0.62 and a high of 0.72 between 1994 and 2008, thus, in Figure 43 the most likely trends in residential electricity consumption would be Gini coefficients that vary between 0.5 and 0.7. Within this cone of sensitivity analyses, it is evident that the impact of income distribution is significant on residential electricity consumption.

If the causality between income distribution and electricity consumption is not considered in energy planning and policy making, it would most likely affect capacity planning and result in a shortage in energy (electricity) required for economic and social development of the country.

Although the simulator results provide an indication of the general residential consumption trends over time, the lifestyles within the low, middle and high income groups differ and contributions towards the electricity component of energy is different. The following section shows the comparisons over time for different deciles as the Gini coefficient changes.

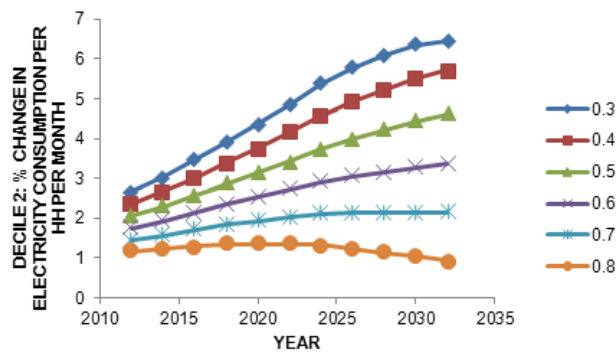
4.2.5 IMPACT OF CHANGING GINI COEFFICIENT ON RESIDENTIAL ELECTRICITY CONSUMPTION PER HH PER DECILE PER MONTH (DM)

Comparative graphs showing the percent change in residential electricity consumption per HH per decile for deciles 2, 5 and then 9 for different runs of Gini coefficient (0.3, 0.4, 0.5, 0.6, 0.7 and 0.8) at a GDP growth of 2% - Figure 45. From the graphical results generated, it is clear that a change to a lower Gini coefficient for decile 2 has a significant increased trend

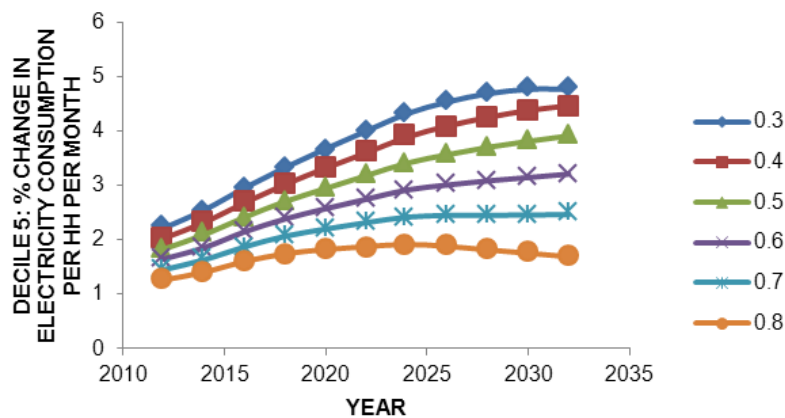
in residential electricity consumption while for the higher income decile 9, the increase is marginal.

These trends may be the result of a number of dynamics:

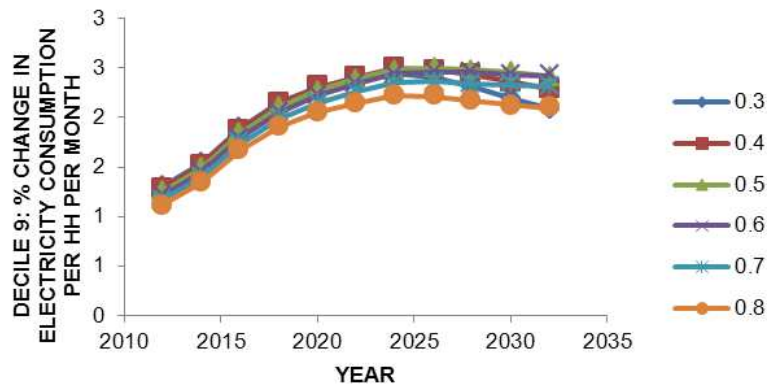
- The lower and middle income deciles can purchase more appliances (fridges, televisions) when disposable income increases, hence requiring more electricity for the use of these appliances, while
- The higher income deciles (who use about 7 times more electricity than the lower income groups) show a levelling off in long-term electricity consumption due to the fact that the number of household appliances requiring electricity cannot increase indefinitely since there is a finite limit to the volume of electricity that can be used. Higher income households are more likely to direct any additional disposable income towards investment and wealth creation instead of even more electricity consumption.



Decile 2



Decile 5



Decile 9

Figure 45: Impact on Residential kWh per HH per Month for Different Deciles – for variable Gini coefficients¹⁵

Besides being causally linked to the savings that can be achieved, the amount of disposable personal income may also be linked to various other factors such as choice of dwelling, food, transport and leisure. Depending on the dominance of these factors, different economic sectors would benefit, for example, if more income is directed towards leisure, the services economic sector is likely to be influenced.

4.2.6 IMPACT OF CHANGING GINI COEFFICIENT ON HH SAVINGS (RANDS) PER HH PER DECILE (DM)

In the following Figure 46, comparative graphs were drawn to observe the change in savings per decile per household for Gini values of 0.3, 0.5 and 0.7.

¹⁵ Figure 44 is Figure 43 disaggregated into different deciles, same Gini trends and assumptions of a GDP growth of 2% apply

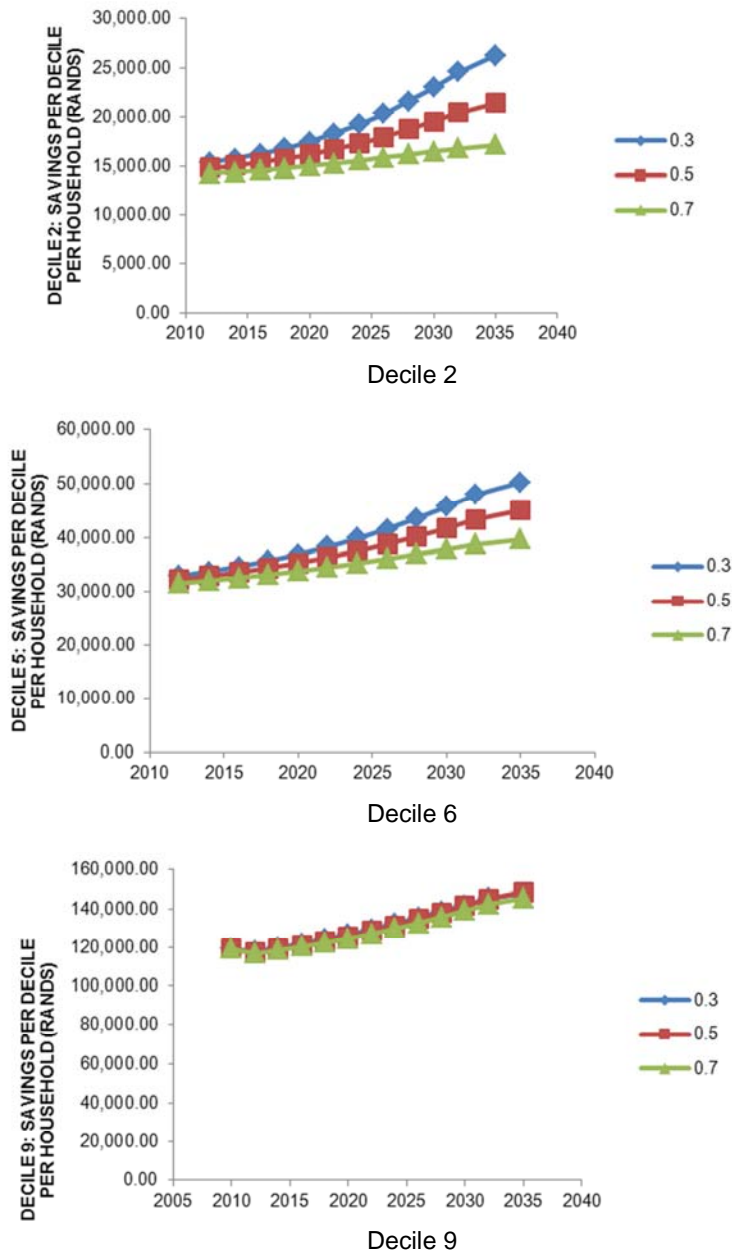


Figure 46: Savings (2005 Rands) per HH per Decile (Deciles 2, 6 & 9)¹⁶

At current levels of income and income distribution, income groups have varying needs so that increased income is allocated towards different needs e.g. electricity consumption, savings, etc. This is reflected in the different savings responses to changes in income distribution (Figure 46).

¹⁶ Figure 45 uses the same Gini trends and assumptions of a GDP growth of 2% as per Figure 43

It is observed that for the low income group (Decile 2), an incremental increase in HH income, does imply an incremental increase in HH savings. The behaviour is slightly different for the middle income group which displays a slightly smaller band HH savings, possibly implying that more income is not necessarily saved but used for luxury goods and to increase the status aspect. Another possible reason for the small savings band in the middle income group compared to the low income group could also be that since the income increases, there is more taxation on the middle income group, thus reducing the overall savings.

In the high income group, there is very little behaviour change of household members to save which could be as a result of using the additional income comfortably on more holidays and more expensive cars since their wealth accumulation in the form of savings and investments may already have been established.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the thesis by presenting the major findings of the key driving forces that affect income distribution, having used a system dynamics methodology. The direct link of changing Gini coefficient on residential electricity consumption is explained. Recommendations for further work in those areas not included this scope are presented.

5.1 CONCLUSIONS

System dynamics has been demonstrated to be a useful methodology to explore the dynamics around income distribution, and although the model excluded many factors, the dynamic behaviour of the income distribution system was feasibly represented. The methodology provided an alternative to the more common modelling techniques such as multiple regression analysis and principal component analysis, with a distinct benefit of modelling multiple variable causalities and feedback loops in the system. It is clear, however, that using system dynamics required a thorough knowledge of the key driving forces that impact income distribution, as well as system dynamics as a method to derive quantitative results.

Changing Gini coefficient has a direct impact on residential electricity consumption. For a GDP growth rate of 2%, until year 2035, a Gini coefficient of 0.5 implies a 3.14% increase in residential electricity demand while a Gini coefficient of 0.4, indicates a 4.73% increase in residential electricity demand. This dynamic is an important consideration for energy planners since government has (and continues to) introduce policies and mechanisms to ensure a more equal income distribution and hence a decrease in Gini coefficient from 0.67 to lower values.

The lifestyles of the low, middle and high income households differ and contributions towards the change in residential electricity consumption with changing Gini coefficient are different depending on the income group. At a GDP growth rate of 2%, changes to a lower Gini coefficient, show a significant increase in the low income households but a marginal increase in the high income households. For the lower income groups, an increase in average income could result in an improvement in lifestyle and the purchase of electricity consuming appliances, however, an increase in average income for the higher income groups could mean greater contributions towards wealth creation through investments instead of

increasing residential electricity consumption, and an indirect economic rebound effect on the economic sectors.

The high income group consumes several times more electricity than the lower income groups but patterns of behaviour over time indicate that this trend tapers off in the long-term. This could be due to the long-term impact on income distribution (depending on which income group is contributing towards the increase in electricity), which will differ after year 2035 since greater wealth investment will again skew the equalisation of income distribution.

Results from the static model showed causality between household structure and income distribution, with an average of 2-person households in the upper deciles resulting in a higher Gini coefficient compared to the baseline, while a 2-person household in the lower deciles, corresponds to a lower Gini coefficient. The exact drivers that result in the difference in Gini coefficient needs to be researched further.

Consideration of various income categories, social grants and free services is important in determining a realistic value for Gini coefficient. Inclusion of all income categories corresponded to a Gini coefficient of 0.71, however, including social grants reduced this value to 0.67 and including free services, further decreased this value to 0.65. The inclusion of social grants and free services are introduced by government as a mechanism to improve income distribution and for that reason, should be accounted for in calculations. The simulated calculations are consistent with those calculated by Stats SA.

The sensitivity of free services such as water, electricity and sanitation were introduced in the simulator by increasing these by 25%, 50% and 75% and calculating the associated Gini coefficient. For all increases in sanitation, the Gini coefficient remained relatively insensitive (change of 0.0001). Increasing the water tariff by 75%, showed an improved Gini coefficient of 0.6170 (down from the base value of 0.6216). The greatest impact on Gini coefficient was obtained by introducing more free basic electricity to the lower deciles (a change to Gini coefficient of 0.5911 from the base value of 0.6216).

Results indicate a large working age population by year 2021. Government's expenditure linked to social spending policies results in a change in income distribution with different time delays e.g. current investment in social expenditures on primary school education may be required to ensure a skilled workforce in 2021 which will impact income distribution, as well as the potential for economic growth in the country. This also means that that workforce will require pension grants and possibly healthcare in a further 15 years (by year 2036). The

demographic age profile correlates with the age dependency ratios over time. The age profiles assist in terms of government planning and can serve as a guideline of which social investments will or should take precedence for long-term benefits.

Electricity intensity for the economy at a GDP growth rate of 2% shows a declining trend, most likely due to the opposing electricity trends for the primary, secondary and tertiary economic sectors. South Africa has higher electricity intensity in the primary sector compared to the secondary sector and higher electricity intensity in the secondary sector compared to the tertiary sector.

5.2 AREAS FOR FURTHER WORK/ RECOMMENDATIONS:

The scope of this project was kept within a small defined system boundary to be simulated using system dynamics but far more insight into additional factors that affect income distribution can be considered for future work. Some areas are explained in this section:

- Further work can be carried out to understand the number of entry level workforce members within the 15-64 age group, since it is expected that if there was a higher number of entry level workforce with relatively lower incomes, the average income in those age groups would have been lower, thus increasing the income inequality measure.
- Contributions of males and females to the paid work sector can also be explored on the hypothesis that if there are more females than males in the paid work sector, the average income for the paid work sector would be lower.
- The average household size for the calculations was set at 3.8 members, however this figure is not constant over time, and further work can be done to explore issues affecting population and household size such as fertility, diseases and mortality rates to get a more accurate representation of household sizes in the future. Again, this dynamic is different depending on the different deciles. It is also recommended that equivalence scales should be used and linked to the household sizes since different members will contribute differently to household income and expenditure.

- Further research can be carried out to determine the key drivers for the decrease in residential consumption at very low Gini coefficients for the higher income group relative to the lower income group, as reflected by the simulator runs.
- More research can be carried out to establish the dynamic behaviour of variables that were kept constant, possibly even by benchmarking against countries with similar societal economies and/or linking these causally to government policy regimes. These variables include:
 - HH current income per GDP,
 - tax regimes, and the
 - HH FCE per GDP.
- More research can also be conducted on the electricity price elasticity effects that will drive consumer behaviour in terms of energy efficiency and possibly fuel switching.
- Further work on the causality and impact of qualifications, education levels and skills development on income distribution, economic growth, entrepreneurship, labour productivity and population growth (with time lag effects is possible).

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