INFRASTRUCTURE IMPLICATIONS OF A GREEN ECONOMY TRANSITION IN THE WESTERN CAPE PROVINCE OF SOUTH AFRICA

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ABSTRACT

In the past decade, international recognition of the effects of climate change, environmental and ecological resource scarcities, and increases in poverty, have led to a growing consensus on the need for a transition towards a green economy. Within the South African context, a green economy transition is recognised as one of the key pathways towards achieving an environmentally sustainable, resource efficient, low-carbon economy. To achieve this transition, however, requires trans-disciplinary, integrated approaches to the management and design of infrastructures across all sectors. Of main interest in this paper is the transport infrastructure in the Western Cape Province of South Africa, which constitutes 10% of the Province's GDP, and is a crucial enabler to other sectors. However, due to the lack of efficiency with regards to cost, energy, emissions and lifestyle within the current transport configuration, a great need to develop a more sustainable system has risen. This paper aims to identify and investigate the complexity involved in response to a green economy transition in the Western Cape Province transport infrastructure system. The research effort examined studies of systems thinking, complex systems and transition theory, which formed the basis for identifying appropriate modelling techniques for evaluating and managing the complex transport infrastructure systems. A review of the Western Cape transport sector shows that complexities do exist in the transport infrastructure networks and may impact society, the economy, and the environment. To evaluate these complexities, systems dynamics was identified as an appropriate approach that can allow the modelling of different scenarios of a green economy transition in the transport sector, and can form the basis for informing policy- and decision-making on development and action plans. Future research efforts will focus on the development of a system dynamics model for the Western Cape transport infrastructure and the analysis of different investment options to enable the transition.

Key words: Transport Infrastructure; Green Economy; System Dynamics; South Africa

INTRODUCTION

In order to meet future goals in reducing the resulting carbon emissions from transport networks, a vast investment into the development of a more energy efficient and sustainable infrastructure is required. The research effort aims to provide realistic indicators of different strategies available to government, including new innovations that are currently being developed, considerations of social, economic, political and technical complexities, which are critical to a more sustainable future.

Research Rationale

The rationale of this research relates to the development of the Western Cape Green Economy Strategy Framework and the green initiatives therein. One of the corner stones of this framework is that of “Smart Mobility”. This framework identifies that the transport sector of the Western Cape constitutes 10% of the GGP and is a crucial enabler to the other sectors (Western Cape Government 2013). However, due to the lack of efficiency with regards to cost, energy, and emissions within the current transport configuration, a great need to develop a more sustainable system has risen. In this regard the ability to model the implications of such developments will greatly assist in the decision-making processes of both private and public investments for implementation.

The analysis of this transition is a difficult progression, one that has to identify and dissect the complex relationships between social, economic, environmental and political counterparts. This has already been undertaken on a national basis in the modelling of the transition towards a green economy in South Africa. This analysis was carried out using an integrated system dynamics model customised to South Africa, developed to investigate the contribution of technology policies to a green economy transition (Musango, Brent et al. 2014). The South African Green Economy Model (SAGEM) was primarily aimed at assessing the impacts of green investments across all sectors on a national basis. Studies have not yet been undertaken to critically analyse and assess the implications of green investments on a regional level, let alone with the focus on a specific sector. Therefore, together with the combined analysis of per sector investments, the critical assessment of the complex systems involved in the implementation of provincial strategic frameworks will provide a solid decision-making platform for provincial government in the transition to a green economy.

Research Objectives

This paper aims to investigate and critically review previous studies about transition theories in order to understand the transition taking place in South Africa and make critical assumptions pertaining to a relevant model. It then becomes necessary to gain a thorough knowledge of the complexity of the systems involved in the infrastructure or transport sector and the relationship it holds with the economy, environment and society. To gain this understanding a comprehensive knowledge of systems thinking, complex systems and the different possible modelling techniques is required in order to form a basis on which to understand and conceptualise the current infrastructure systems in the Western Cape Province of South Africa.

CONTEXUALISING THE RESEARCH

Transition to a Green Economy

The United Nations Environmental Programme (UNEP) defines a green economy as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP (b) 2013). Put simply, a green economy is one in which the growth in employment and income is governed by both private and public investments that aim to reduce carbon emissions and enhance energy and resource efficiency whilst protecting biodiversity and ecological services. With this, a green economy has the potential to address the pressing problems of unemployment, poverty, food and water security, energy sufficiency and environmental degradation. This provides an enticing incentive for developing countries to make such investments. However, the capital required to do so, remains the crippling constraint in such endeavours. It is at this point that an integrated model that can predict outcomes including the costs and benefits of sustainable developments becomes important to the decision-making processes involved.

In response to the justified push towards a green economy transition, South Africa's Green Economy Accord recognises the potential to create sustainable and equitable jobs, agreeing to a goal of creating 300 000 green jobs by 2020 (Economic Development Department 2011). In response to this the Government set up the Green Economy Fund in 2012 with the allocation of 800 million Rand aiming to facilitate investments in green initiatives (Department of Environmental Affairs 2012). These and many other policies and programmes attribute to a commitment by government to move towards a green economy, all that is required are incentivised and realistic initiatives that through accurate analysis have been proven to be attainable and equitable.

Sustainable development in the Western Cape Province of South Africa

The central emphasis of the transition to a Green Economy is the need to address climate change, the primary policy response to this is the National Climate Change Response (NCCR) White Paper (2011). The strategic priorities outlined in this document, provide the direction of action and responsibility for the different levels of government. Section 10.2.6 of the NCCR states that; "Each province will develop a climate response strategy, which evaluates provincial climate risks and impacts and seeks to give effect to the National Climate Change Response Policy at provincial level" (Department of Environmental Affairs 2011). In response to this the Western Cape Government created the Western Cape Green Economy Strategy Framework with growth in green investments and market opportunities sitting at the core of the strategic framework.

Identified as a country leader in green initiatives, the Western Cape emphasises the need for their principle drivers to have the ability to deliver both economic activity and improved environmental performance (Western Cape Government 2013). This framework aims to use the region's existing economic strengths to positively impact the lives of the poor and at the same time deliver results. Whilst this remains an attractive mode for transition, the responsibility falls onto local government to plan and respond to climate change amidst the demanding challenges that the future holds. The South African Local Economic Development (LED) Network identifies these challenges as being: limited skill development and capacity at a local level, persistent short-term needs diminishing already limited funds and the inability to predict with any certitude the necessary adaptions for future conditions

(South African LED Network 2010). All of which form the setting of the emerging need to prepare provincial governments towards a green economic transition, which is evidently one of great difficulty.

Infrastructure developments globally and in the Western Cape

Over the past decade a global emphasis to reduce carbon emissions and improve economic efficiency in the transport sector has been made on many levels. This comes as no surprise as 22% of carbon emissions from fossil fuel combustion globally are derived from the transport sector (International Energy Agency 2013). This in turn has led to Government emphasising the need to transform the current inefficient infrastructure system and invest in new innovations leading to more sustainable transportation. The Green Accord identifies the reduction of carbon-emissions on the roads as one of its key commitments, including large investments into improved mass transport systems and a shift to rail for freight transport (Economic Development Department 2011).

The Western Cape Government through its green initiative has acknowledged a number of opportunities available for investment, such as: better transport planning, improved public transport as the crux, home-grown minibus-taxi service innovations, efficiency in private transport, local development and adoption for cleaner energy for motor vehicles, and progressive infrastructure improvements for non-motorised transport (Western Cape Government 2013). Additional developments including the better design and maintenance of road infrastructure and improved land use planning would need to be acknowledged. The importance of informal transport services meeting the needs of the urban poor in inaccessible areas at affordable prices would also need to be stressed (Figueroa, Fulton et al. 2013). The demands on such services would require fuel subsidies and incentives for private vehicle owners to move towards more sustainable modes of transport. All of which are sound notions, but still require a vast amount of insight into the complexity of the associations between these different initiatives on all levels.

Systems Thinking

The previous discussion over what the green economy transition is and how it relates to the South African context forms the backdrop to investigating the different pathways to a more sustainable infrastructure system. To better understand and assess the measures that the Western Cape is taking to promote sustainable developments in this milieu, an understanding of the complexity of the different systems at work is required.

Systems' thinking is a field of knowledge that aims at understanding change and complexity within the collection of parts comprising the system itself and the relationship the system has with its environment. The underlying complexity of all systems is studied through the dynamic cause and effect over time (Maani, Cavana 2007). This particular definition further identifies three distinct but related dimensions namely; paradigm, language and methodology. The paradigm of systems thinking is described as being the way of thinking about the world and relationships. Emphasis is put on the ability to see the big picture and how interrelated parts within the system interact in a dynamic non-linear manner with an understanding of the operations between the counterparts. The language and methodologies involved in systems thinking are tools used to understand and model the behaviour of the system and are described later.

The ability of systems thinking to conceptualise real world complex scenarios has led to its popularity in many fields. The framework created by this results in a manner of problem solving that considers the problem in its entirety, involving pattern finding to enhance the understanding of and responsiveness to the problem at hand (Rubenstein-Montano, Liebowitz et al. 2001). Further consideration of how the system is influenced by its environment and how this effects the solving of the problem is taken. The emphasis on the relationships among the parts of the system, rather than parts themselves, makes systems thinking a powerful approach to problem solving (Schiuma, Carlucci et al. 2012). This combination of understanding the individual counter parts of the system, as well as the inter-linkages and relationships between these parts, adds to the benefits of applying such a thought process.

The basic methodology of modelling with a systems thinking framework can be applied to almost any complex problem and thus can be used as a useful tool in understanding the infrastructure implications involved as the crux of this investigation. This methodology is outlined by (Maani, Cavana 2007) as the five phase process of systems thinking and modelling as illustrated in figure 1.

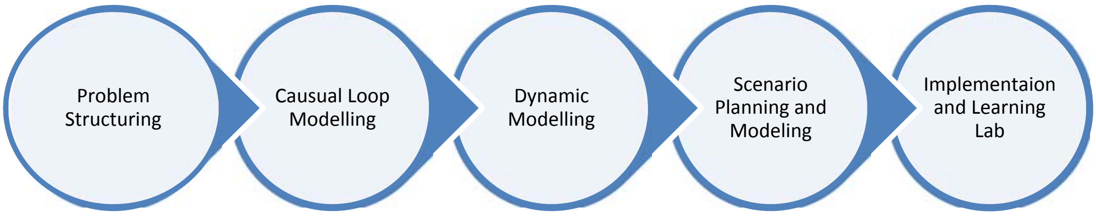

Figure 1: Phases of systems thinking and modelling methodology

This method, although briefly described here, provides a rigorous way in which to visualise, share and communicate the evolution of complex organisations and issues over a dynamic time period. This framework further provides a solid platform on which to solve problems and create designs while mitigating unwanted surprises in the process.

Understanding Complex Systems

The nature of a green economy inherently means that a range of different systems need to interact in a cohesive way in order to create the most efficient and beneficial situation. For example; engineers were traditionally concerned about technological complexities, whilst both social and environmental planners focussed on social and bio-physical complexities respectively. The necessity for these skillsets to overlap is paramount to the success of a green economy. This calls for change agents to be "heterogeneous engineers", able to work across material, physical and social boundaries in situations of dynamic emergent complexity (Kane 2010).

The concept of complex systems is difficult to define; there exist many different interpretations based on different principles. However, an attempt to better understand complex systems requires the breakdown of the concept itself. The term systems can be defined as groups of interacting interdependent parts linked together by exchanges of energy, matter and information (Costanza, Wainger et al. 1993). The definition is taken further by explaining how "*complex systems are characterised by strong (usually non-linear) interactions between these parts, complex feedback loops* *making it difficult to distinguish between cause and effect, and significant time and space lags, discontinuities, thresholds and limits*" (Costanza, Wainger et al. 1993).

The definition of a complex systems leads onto the theory that facilitates the use and understanding of the concept in its entirety, otherwise known as Complexity Theory. This interdisciplinary field provides the framework by which groups of connected components that influence each other can be analysed and assessed. Complexity theory involves the characterisation of the different features of complex systems as described by (Rotmans, Loorbach 2009) to be the following:

i. Complex Systems are open systems that are constantly interacting and evolving with their environment over time.
ii. Interactions between components in complex systems are generally non-linear.
iii. Complex Systems have feedback loops being both negative (damping) and positive (amplifying).
iv. Complex systems have history, creating path dependence whereby current and future states depend on the path of previous states.
v. Complex systems are nested on various organizational levels, having emergent properties, implying that higher level structures arise from interaction between lower level components.
vi. Complex systems have multiple attractors being a preferred steady system's state set.

Complex systems can be further modified to have the capacity to react and change from learnt experience; in other words, they are able respond and adapt to a dynamic environment. This type of system is called a Complex Adaptive system (CAS) and is defined as a dynamic system able to adapt in and evolve with a changing environment, emphasising that there is no separation between a system and its environment in the idea that a system always adjusts to a changing environment (Chan 2001). From this explanation, the nature of infrastructure networks and systems can be described as being complex systems. Such that they are a compilation of many different components collaborating with one another yet still acting independently of each other, whilst being influenced by an ever changing environment.

Understanding Sustainable Transition Theory

Having identified the necessity and desire for a transition to a more sustainable future by most governments and societies, the issue of how to promote and govern this transition toward sustainability arises. The complexities of the mechanics that drive the different systems involved in this change as aforementioned create an array of fundamental sustainability challenges faced by policy-makers.

These sectors can be conceptualised as socio-technical systems consisting of actors and institutions interacting to provide specific services for society. For example; the emergence of the transport system with the development of automobiles required a complementary development of road infrastructure, fuel supply systems, traffic rules and services. All of which involved technological, material, organizational, institutional, political, economic and socio-cultural changes, which form the basis of a socio-technical transition (Markard, Raven et al. 2012). Such transitions have further effects on societal domains, leading to the broader idea of sustainability transitions, which Markard et al. (2012) defines as "*long-term, multi-dimensional and fundamental transformation processes through* *which established socio-technical systems shift to more sustainable modes of production and consumption*". Furthermore, four frameworks have been realised in more theoretical terms, including; Transition Management, Strategic Niche Management, Multi-level Perspective, and Technological Innovation Systems.

Table 1: Analysis of Sustainable Transition Theories

Transition Framework	Description
Transition Management	Aims to combine ideas on technical transitions with insights into complex systems theory. Seen as an analytical lens to assess how societal actors handle complex societal issues at different levels, resulting in the development and implementation of strategies to influence the 'natural' governance processes (Lorbach 2010).
Strategic Niche Management	Introduced to trigger off regime shifts by the deliberate creation and support of different niches. Conceptualised as protected spaces, being specific markers or application domains, in which radical innovations can be developed without being influenced by regime pressures (Markard, Raven et al. 2012). Green niches have been defined as spaces where networks of actors experiment with and mutually adapt to greener organisational forms and more eco-friendly technologies (Smith 2007). Viewed as the building blocks of certain technologies, facilitating innovative journeys for broader societal changes towards sustainable development (Schot, Geels 2008).
Multi-level Perspective	Multi-dimensional (technological, political, socio-cultural, and economic) nature of sustainable developments. Explains technological transitions by the interaction of the forces at work on three different levels: niches, regimes, and landscapes (Markard, Raven et al. 2012). Conceptualises the overall dynamic patterns involved in socio-technical transitions by investigating the interplays between the three different levels (Geels 2011).
Technological Innovative Systems	Concerned with the emergence of innovative technologies and the institutional and organisational changes that are required to accommodate new developments (Markard, Raven et al. 2012). Firms and actors of institutional infrastructures become the important drivers behind novel technologies and sustainable developments. The components of an innovation system are the actors, networks contributing to overall functionality, diffusing and utilising new products (goods and services), and process institutions (Bergek, Jacobsson et al. 2008).

System complexities of the Western Cape Infrastructure

Having identified an infrastructure network as a complex system, a better understating of what an infrastructure system is now required in terms of its complexity. Often referred to as the backbone of a nation an infrastructure system can be defined as a network of independent, manmade systems and processes that function in collaboration with one another to produce and distribute a continuous flow of essential goods and services (Ouyang 2014). This means that each system has to function effectively in order to uphold the integrity of another system, whilst still controlling and adapting to its own set of dynamic factors

The transport infrastructure systems in the Western Cape comprise many different facets that can be broadly characterised into passenger transport and general freight transport. These networks generally comprise airports, ports and harbours, roads and public transport, and rail lines all of which comprise complex relationships between key developments in society, the economy and the environment. This chapter aims to describe the different infrastructure networks of the Western Cape and identify the many system complexities that exist within and between the networks in light of the above mentioned key development outlooks.

Airports

The Western Cape has two well-developed airports; the Cape Town International Airport and the regional George Airport, both of which serve the commercial air transport sector within the province. The George airport handles over 600,000 passengers each year due to the areas large tourist economy (Airports Company South Africa 2014). It is also a national distribution hub for cargo such as flowers, fish, oysters, herbs and ferns all of which attribute to a growing dependence of the regions agricultural exports on the systems service performance. Cape Town International Airport is the third biggest airport in Africa serving a multitude of international flights and is expected to accommodate over 14 million people in the year 2015 according to ACSA. Forming a central hub to the tourism economy of the Western Cape the airport plays a central role in achieving the key development plans of the province. These networks in themselves have many complexities, but also exist as important sectors of the broader transport network of the Western Cape in which the relationships with other systems are paramount to the smooth running of all infrastructure services.

Ports and harbours

With approximately 96% of the country's exports being conveyed by sea through the eight major ports of South Africa, two of which are situated in Cape Town and Saldanha. Port expansion is heavily dependent on the national, regional and global economy as well as the ports competitiveness of pricing both locally and internationally (Palmer, Graham 2013). The Western Cape infrastructure framework further describes that any development occurring in the Cape Town port area requires environmental approval for seaward expansion and improvements to back-of-port logistics networks. This legislature alone sheds light on the environmental impact that ports can have and the importance thereof to maintain a stringent control of future developments but also the necessity for more sustainable investments in these sectors.

Cape Town port is the second busiest container harbour in South Africa, in the 2011/2012 financial year the port handled 2775 vessels for a gross tonnage of 51 million GT (Ports.co.za 2014). With this the port remains as the largest exporter of fruit and has a busy fishing industry including many shipyards used by international companies for carrying out repairs. The Saldanha Bay Port is a key exporter of iron ore from the Sishen mine in the Northern Cape as well as steel and oil from the surrounding industries. Both ports exist as key strategic and economic assets for South Africa, placing importance on managing any transitions occurring within the ports with the upmost certainty.

Roads and Public Transport

The road infrastructure existing in the Western Cape consists of 6400 km of paved network and 10 500 km of gravel network. This is testament to the substantial agricultural sector that exists within the province. Only 63% of the paved network is deemed to be in good condition according to the Western Cape infrastructure framework due to the increase in heavy freight traffic on the roads (Palmer, Graham 2013). This problem results in an insurmountable maintenance backlog on all of the roads, coupled with a critical shortage in funding both provincial and municipal. One of the key factors in the deterioration of the roads is the increase in road freight traffic which is exceeding the design load capacities of even the national roads. This comes as a result of an inefficient rail service and a lack of confidence by industry to transport large volume goods by rail due to the inflexible nature of the service.

With a society that is generally reliant on either private automotive transport or public taxi/bus services the roads in the province play a vital role in the success of the economy. With the number of motorised trips projected to increase substantially in the near future, the demand for a reliable passenger transport service has become a top priority for future developments. Already the Bus Rapid Transit (BRT) is being progressively implemented in the Cape Town city area with notable success however as a proportion of total commuters, volumes remain fairly low (Attwell 2012). There still remain large improvements to the public transport networks with respect to the key challenges of safety and security, dedicated and integrated passenger transport services, stakeholder and user participation, the minibus taxi industry, and bus services (Department of Economic Development and Tourism 2005).

Rail and Freight Transport

The Western Cape Infrastructure Framework of 2013 identifies the current split between road and rail freight transportation to be 14%rail and 86% road freight. This is a concerning fact as South Africa has the largest rail network on the continent and yet is failing to utilise this important piece of infrastructure. This comprehensive spilt has been recognised as resulting from a lack of performance and market orientation within Spoornet[1] (now Transnet) operating in a rail monopoly type structure (Department of Economic Development and Tourism 2005). The rail infrastructure has historically suffered from underinvestment resulting in the poor maintenance and growth of the vast network systems. It exists as a great opportunity for investment that will have far reaching benefits for broadening public transport, reducing carbon emissions and reducing road congestion.

The public transport transitions of the future will focus on increased passenger rail and integrated Rapid Transit (IRT), with investments into non-motorised transport in urban centres and shifts from road to rail freight traffic, all of which stand to benefit society, the economy and the environment. However each network in itself is a vastly complex system dependent on many external factors and relates to all other systems in many different ways. The nature of these complexities makes it almost impossible to envisage the future outcomes of any investments without the use of techniques and strategies for modelling complex systems.

[1] South African rail transport company, a state controlled organisation

APPROPRIATE MODELLING TECHNIQUES

Having identified different frameworks and strategies to help understand and contextualise the complexities of transition management, the next step to comprehending those changes is to formulate and develop models to analyse certain scenarios. There exist many different modelling techniques that can be broadly categorised into five approaches: empirical, agent based, economic theory based, and system dynamics based. A brief introductory review on the different techniques associated with the topical case of infrastructure systems will be provided in order to develop a conclusive rationale for using a system dynamics approach.

Empirical Approaches

The empirical approach analyses the interdependencies according to historical accident or disaster data and expert experience (Ouyang 2014). This approach would therefore identify common significant failure patterns and be able to quantify the strength of associated interdependencies. This would enable informed decisions to be made in conjunction with an empirical based risk analysis and also provide alternative measure to mitigate those risks. Difficulties arise in identifying all interdependencies within these systems and capturing relevant and tangible historical data for analysis, as many sources originate from media driven outlets.

Agent Based Approaches

An effective way of analysing the inherent complexity of infrastructure systems is the agent based approach, which adopts a bottom-up method assuming the complex behaviour emerging form many individual and relatively simple interactions of autonomous agents (Ouyang 2014). These agents interact with others as well as their environment based on a set of predetermined rules which reflect the manner in which that agent would react in the real world. An agent can be defined as a computer system situated in some environment that is capable of flexible autonomous action in order to meet a defined set of goals (Chappin, Dijkema 2010). There do remain some weaknesses, being that the quality of simulations are often dependent on the modellers assumptions and that calibrating the simulation parameters can be very difficult due to a lack of relevant data.

Economic theory based

For a market economy there exist mainly two types of players, namely producers and households. These so called players interact in a continuous cycle, where households offer labour and capital to producers in exchange for payment. The producers also provide goods and services not only through labour and capital but various types of processed materials. Otherwise known as econometrics; this type of modelling measures the relationship between multiple variables by running analysis of historical data in order to find correlations to the specific variables (Bassi 2014). The structure of the system runs on three stages; specification, estimation, and forecasting specified by a set of equations describing both physical and behavioural relations. Again the downfalls of this framework arise in the difficulties experienced in the calibration of production functions when data is limited.

System Dynamic Modelling

Used in a diverse collection of areas, System Dynamic (SD) models have become an important tool for analysing and making difficult normally complex managerial decisions. This approach makes use of a top-down method to assess complex adaptive systems over long periods of time. The unique and beneficial attributes of this technique are the use of feedback loops and stock and flow elements to help understand nonlinear systems. Feedback loops identify the connection and direction of effects between the components of complex systems whereas stocks represent the quantities or states of the system, controlled over time by flow rates (Ouyang 2014). In other words feedback loops permit information resulting from some action to travel through the system and return to its original point (System Dynamics Society 2011), thus creating the ability to influence future actions. To capture the causal influence among the different variables of a system a causal-loop diagram is used in conjunction with a stock-and-flow diagram which describes the flow of information and products through the entire system.

The ability of this approach to be used in so many different scenarios, be it in a quantitative or qualitative system, lies in the assumption that the behaviour of the system is to a great effect caused by its own structure (Pruyt 2013). These system structures are comprised of physical and informational aspects important to the decision making process of a system and may also include other features such as policies, traditions, securities and strategies. Pruyt (2013) goes further to explain that in order to improve unwanted behaviours of the system, the structures governing the system must be changed. System Dynamics provides the framework required to identify and then test desirable changes to a system in a virtual setting.

The functions attributed to this type of modelling would enable decision makers to determine the consequences of green investments into infrastructure in response to the green economic transition. This would include the expected disruptions to existing infrastructure and socio-political practices, as well as the exploration of the mechanisms behind the outcomes in order to evaluate certain risk mitigations. The ability to reflect the evolution of long-term effects of policy and technical changes would provide accurate investment recommendations as well as the ability to compare alternative infrastructure development strategies. This would in turn help to build a growing consensus between policy makers and potential stakeholders in green investments.

There do however remain some drawbacks to system dynamic approaches, which often require the integration of other modelling approaches to provide a uniform analysis framework. These weaknesses include; the semi-quantitative nature of casual loop diagrams as well as the many functions and parameters in the model that require calibration being data intensive. This leads to the greatest problem being the acquisition of relevant data resulting in only conceptual validation efforts, which limit the model.

Principles of System Dynamics

The process of utilizing system dynamics in problem solving and analysis is broadly characterised by five main steps; problem formulation, conceptualisation, formal model building, model testing, policy formulation and testing. For the scope of this article the first two steps will be undertaken as part of a greater research initiative. In order to firstly gauge the greater scope of the research effort and the system dynamic processes involved, a summation of the system dynamics approach is provided (System Dynamics Society 2011):

i. Defining problems dynamically, over time.
ii. Looking at behavioural views of the significant dynamics of a system.

iii. Conceptualising the real system as continuous quantities, interconnected through causal feedback loops.
iv. Identifying independent stocks in the system and their flows rates.
v. Formulating a behavioural model capable of reproducing the complexity of the problem, generally expressed in nonlinear equations.
vi. Developing applicable policy insights through understanding the resulting model.
vii. Making informed changes as a result of model-based understandings and insights.

Problem formulation involves the identification of a specific problem that is of greatest concern to the relevant stakeholders. This involves the identification of key variables to be considered as well as the time horizon of the problem itself and the analysis (Maani, Cavana 2007). Other key aspects include the collection of information and data as well as organising group discussions with the relevant stakeholders concerned with the problem.

The conceptualisation or dynamic hypothesis formulation involves the investigation of current theories of the problematic behaviour. The dynamic hypothesis aims to explain the dynamics as endogenous consequences of the feedback structure (Maani, Cavana 2007). The mapping of the available data and gathered information is developed through causal loop diagrams (CLD) or system archetypes. These diagrams are based on the initial dynamic hypothesis, key variables, reference modes and available historical data.

Causal loop diagrams are used to determine the nature and direction of the relationships within the system between the key variables that are identified. From the CLD, stock and flow diagrams can be created from which the modelling process can begin. In defining the causality of the problem scenario, there exist different types of feedback loops which are important in understanding the problem. These include reinforcing loops which are positive feedback systems often representing growing or declining actions. On the contrary, balancing loops seek to stabilise or return to control, aiming for a specific target. In all CLD's the nature of the feedback loops are identified and indicated in order to better conceptualise the problem.

An easy example to illustrate the nature of the CLD feedback loops is that of population. In Figure 2**Error! Reference source not found.** there exist two feedback loops, one being reinforcing (births) and one balancing (deaths). The understanding of the causality of the reinforcing loop can be described as the more births there are the more the population will be and the more the population is, the more births there will be. This is an example of a growing reinforcing loop for which the plus signs indicate a positive move of each variable in the same causal direction. The balancing (deaths) loop can be described as the more the population, the more deaths there will be, but the more deaths there are, the less the population will be. In this regard the specific terminology is used in order to show the relationship and direction of influence between the variables. The positive and negative signs indicate the way in which one variable moves or changes direction in relation to another, with (+) being movement in the 'same direction' and (-) being movement in the 'opposite direction'.

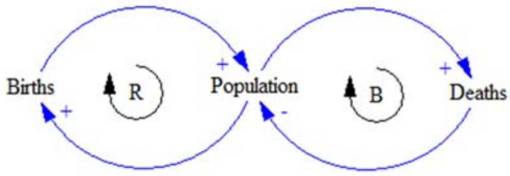

Figure 2: Population example of causal loop conceptualisation

CONCEPTUALISATION OF THE PROBLEM

The conceptualisation of the problem in modelling the infrastructure implications caused by a transition to a green economy aims to identify the dynamic relationships between the different transport actors. The model boundary and causal loop diagrams are formed by the modeller in order to understand the nature and direction of the existing relationships between key variables. For the proposed model a time horizon beginning at the year 2000 ending in the year 2040 will be used. This is in conjunction with the Western Cape government's strategic framework for future infrastructure improvements. The key variables and recognised stocks are provided in **Error! Reference source not found.** and form a model boundary of the proposed simulation based on the modeller's understanding of the problem.

Table 2: Key variables and recognised stocks of sub-models

Endogenous			Exogenous	Excluded
Stocks	**Flows**	**Auxiliaries**	**Parameters**	**Excluded**
Road Network				
Roads under Construction	-Road construction starts -Road completion	- Average Road cost per km - Budget for Road construction - Road Maintenance cost - Time to Complete Road - Relative km of Road	-Initial Road Cost per km -Average Budget - Time -Initial km of Road	-Elasticity of road density
Functioning Roads	-Road completion -Road disruption	- Average Road Life without maintenance - Effect of Maintenance on road life - Effect of increased truck haulage on roads - Motor vehicles effect on roads - Fraction of road maintenance achieved	-Initial Road network -Effect of maintenance on road life -Truck haul effect -Motor vehicle disruption effect	-Road Design Life comparison -Equivalent E80s for vehicle growth -Road category
Roads Infrastructure Expenditure	-Yearly expenditure	-Time	-Initial transport infrastructure expenditure -Government Expenditure on Road Infrastructure	-GDP deflation

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Endogenous			Exogenous	Excluded
Stocks	**Flows**	**Auxiliaries**	**Parameters**	**Excluded**
Cost of Road Maintenance	-Changes in road maintenance cost	-Cost of road maintenance growth rate	-Initial road maintenance cost per km	
Population				
- Population of Western Cape	-Births -Deaths -Domestic migration in -Domestic migration out	-Death Rate -Birth Rate	-Estimated migration In stream table -Estimated migration Out stream	-International migration -South African population relation
Transport				
- Motor Vehicles	-Vehicle sales -Vehicle disposal	-Desired vehicle stock -Desired vehicle ownership per capita -Relative motor vehicles -C02 emissions	-Average vehicle life span -Access to vehicles -Percentage increases of other passenger transport modes -Average C02 emissions per vehicle -Average C02 emissions per Truck load	-Trips taken -Passenger trips increase
- Total Freight Transport	-Yearly Freight Increases	-Growth of Freight per year -Rail Freight -Road Freight -Number of trucks -Relative number of trucks	-Growth in GDP -Rail/Road Freight modal split -Change in modal split due to green investment -Average haul distance per year (trucks) -Average freight load -Average C02 emission per train haul	-Agricultural haulage -Postal Services
GDP				
- GDP	-GDP Growth	-GDP growth rate -Real GDP per capita -Relative real GDP -GDP Previous year	-Growth Trend	

Endogenous			Exogenous	Excluded
Stocks	Flows	Auxiliaries	Parameters	Excluded
Green Economy Investment				
- Green Economy Transport Infrastructure Investment	-Operational budget per annum -Capital Budget	-Improve Public Transport -Expand and Improve performance of rail system -Integrated Rapid transport -IRT operating expenditure	-IRT Capital expenditure -IRT project expenditure -Investment into conventional bus fleet -Investment into Metrorail -Investment into minibus taxi fleet -Expenditure on freight rail	-Investment into non-motorised transport -Investment into biofuels

Although this investigation is primarily centred on the implications of a green economy transition on the infrastructure network of the Western Cape, it is still necessary to envisage the effects across all sectors of the economy in order to understand the problem. For this the CLD (**Error! Reference source not found.**) illustrates the dynamics involved between the different sectors of the economy, society and the environment with in a Green Economy transition. The orange loops illustrate the key variable involved in the infrastructure framework and how they interact with other sectors of the economy. It can be seen in loop B2 how a move to more freight being transported by rail instead of road will decrease the amount of CO_2 emissions and thus lessen the effects of climate change. The infrastructure network is very closely linked to biofuel production which in turn will directly influence food crop production and the Gross Regional Product (GRP). The agricultural sector is very closely linked to the water services of the province in terms of pollution from fertilisers and pesticides in the catchment areas. CO_2 emissions from the biofuel, infrastructure, agricultural and energy sectors will influence the effects of climate change which will in turn play a large part in the available water supply for the population. Other important enablers of the economy include that of Education, Employment and Health care which are all influenced by the growth in population and the government expenditure provided by economic growth and stability.

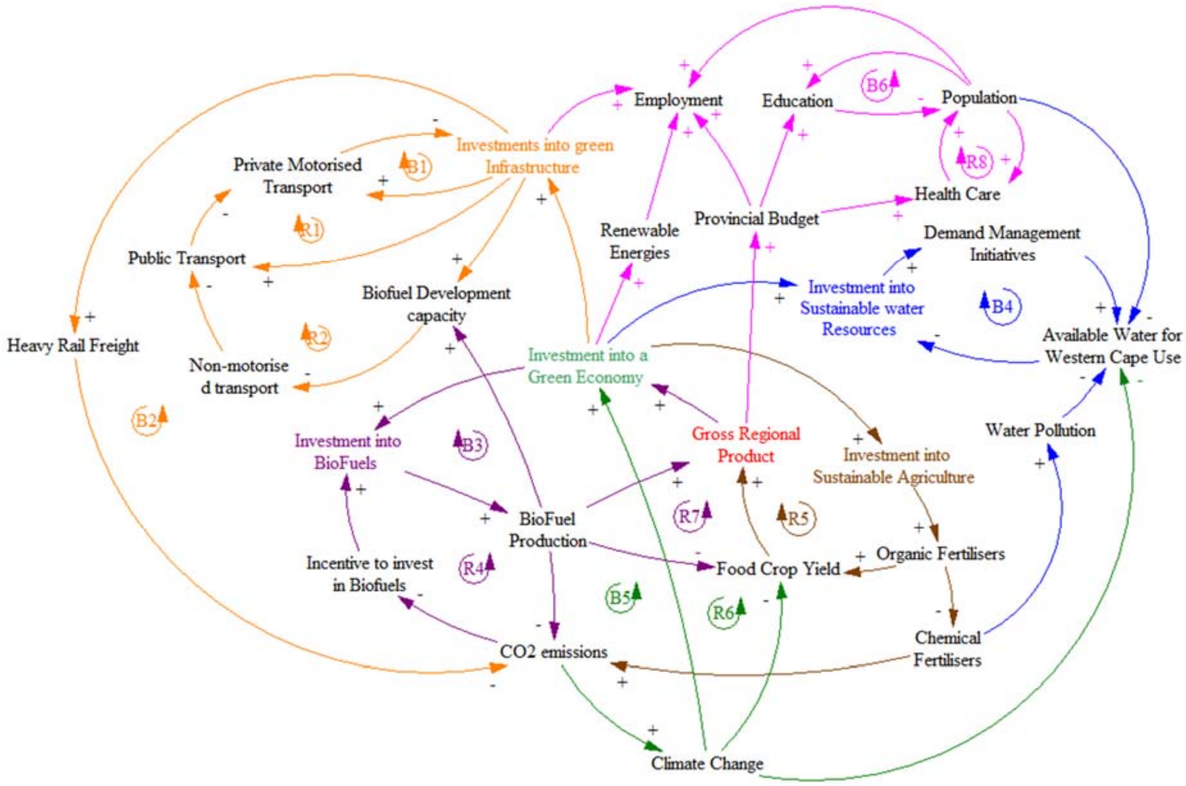

Figure 3: Causal Loop Diagram for the Western Cape Green Transition

The dynamics of the roads infrastructure problem, coupled with the green economy investment initiatives, are mainly dependent on the functionality of the roads and the GDP-related expenditure on transport infrastructure. The various loops illustrated in **Error! Reference source not found.** are colour coded to indicate the different balancing and reinforcing loops existing in the problem scenario. With regard to the afore mentioned key causal loop (pink) it can be seen that an increase in the GDP of the Province allows for a greater budget for transport infrastructure expenditure, this in turn increases the amount of roads under construction leading to a functioning road network. With more construction and functionality of the road network the demand for expenditure in those areas decreases allowing for growth in other sectors ultimately benefitting the GDP.

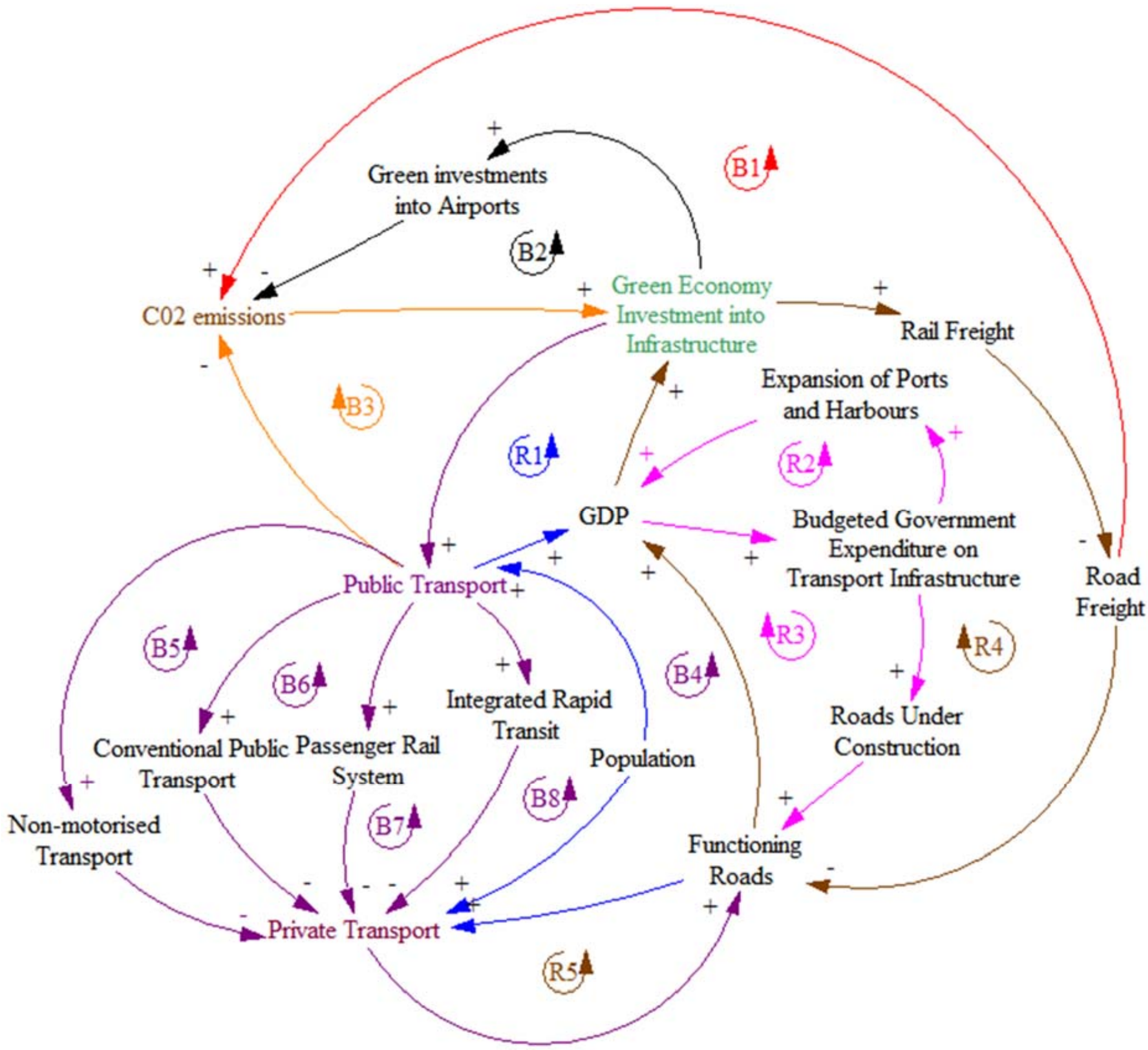

Figure 4: Causal Loop Diagram for the Transport Infrastructure Network in the Western Cape

The other important loop is that of a green economy investment into public transport (purple) resulting in an increased usage of Conventional public transport modes, passenger rail and integrated rapid transit (MiCity busses). These investments will decrease the amount of private motor vehicle transport thus having less impact on the roads resulting in the life span of functioning roads being enhanced. With more functioning roads the whole infrastructure system is made more efficient and thus less expenditure will be necessary to spend on construction making room for other GDP enabling ventures therefore GDP increases. Importantly investment strategies into freight rail can be expected to lessen road freight haulage having effects on both $C0_2$ emissions and the functionality of road infrastructure.

CONCLUSION

The final objective of this research is to create a knowledge base of the different systems and complexities within the transport sector of the Western Cape. This will involve investigating the interplays between society, economics and the environment in identifying how the transport sector operates and the importance it holds on all levels. Consideration of the dependencies of other sectors on infrastructure will also be investigated to emphasise the importance of making the green transition.

This paper introduced the concept of systems thinking and the importance it holds in the making of managerial decisions based on a holistic view of the real world situation. The nature of complex systems was investigated in order to better understand how a proposed infrastructure transformation to a green economy shift would play out over time. To fully understand the complex nature of a transition to a green economy, different transition theories instrumental to the thought processes and approaches to the modelling and hypothesising of the topic were investigated. This was followed by a brief analysis of a number of modelling techniques that exist as ways of conceptualising the complexities of a transition to a green economy. Using the theories and concepts uncovered in the paper, a brief investigation of the current transport infrastructure for the Western Cape was undertaken. This investigation shed light on the current problems that exist and the requirements for future developments, illustrating the intricate relationships that exist between the different transport networks and the socio-economic and environmental impacts they have.

This paper forms part of a greater research effort in the investigation of the infrastructure implications of a transition to a green economy. The literature review here introduces and analyses the complex dynamic nature of the situation and identifies many different ways of understanding and then modelling the transition at hand. It became apparent that the infrastructure networks existing in the Western Cape are highly complex and through an aggregate CLD it was possible to conceptualise the scenario. From the problem conceptualisation and brief description of the model boundary the modelling process can begin. The model will aim to envisage the current infrastructure network and analyse certain policy and investment scenarios over time.

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