

THE TRANSITION TO A GREEN ECONOMY: A SYSTEMS APPROACH TO MANAGING TECHNOLOGY

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BIOGRAPHY

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ABSTRACT

The transition to a low-carbon, resilient economy – or the green economy – will place an emphasis on the management of infrastructure, including its planning and design. This management emphasis, in turn, requires transdisciplinary, integrated approaches, since our academic and industrial organisations have great expertise in system components, but still lack experience with the management of the ‘systems of systems’ that constitute our infrastructure at the total societal level. This research effort, then, aims to improve our understanding of how technical, economic, political and other socio-ecological factors interact, and to develop the associated capacities and capabilities, particularly in the context of great uncertainties as we embark on the transition. In this way, specifically, the practice of technology management may be improved. The focus then is on analysing future trends in infrastructure and technology development to enable the socio-technical transition to a green economy. The paper uses the Western Cape Province as a case study, as well as the system dynamics modelling approach, to understand future developments and what this might entail for technology management. The results show how technology management must account for high uncertainties with associated significant investments that underpin the necessary transition in the Province, pertaining to renewable energy, transportation and the agricultural sector.

Keywords: Sustainability, green economy, transitions, systems thinking, technology management

INTRODUCTION

The transitioning to a low-carbon, resilient economy, also referred to as the ‘green economy’, requires a concerted effort from different scientific disciplines. The United Nations Environment Programme (2011) defines a green economy as “an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities”. Further, to facilitate this sustainable transition, appropriate research and development efforts that are transdisciplinary in nature are necessary. Such efforts will require knowledge co-creation with societal

participants that are intrinsically involved with real-world complex problems (Regeer and Bunders, 2009), which, in essence, are linked to the problems relating to infrastructure.

The transition implies the modernisation of infrastructure systems, which is a significant challenge. New technologies offer promising opportunities for improvement. However, many infrastructures have been difficult to transform effectively and efficiently. Hansman et al. (2006) highlight that nearly all aspects of infrastructure are organised around institutions that emerged and became codified during the late nineteenth and twentieth centuries. In general, these systems evolved through incremental changes in technology, markets and regulatory processes. As we embark on the transitioning journey, however, all sectors face (in varying degrees):

- discontinuous and rapid shifts in technology;
- deregulatory pressures;
- associated greater fluctuations in demand;
- natural and human threats to operations;
- unanticipated forms of competition;
- impacts of information technology on the organisation and management of work; and
- changing societal needs and expectations.

In terms of the latter especially, and within the South African context, the Government has adopted several policies that have an explicit aim of achieving a transition to a green economy. These include (Department of Environmental Affairs [DEA] and United Nations Environment Programme [UNEP], 2013): the National Development Plan, the New Economic Growth Path, the Industrial Policy Action Plan, the National Strategy for Sustainable Development, the Climate Change Response Strategy, the Global Change Grand Challenge programme, as well as many sector-specific strategies; for example, water, transport, waste, energy and biodiversity.

Most provincial governments and metro municipalities have also established their own green economy strategies. At the same time, South Africa has entered into global agreements and processes where the green

economy is defined explicitly as the long-term goal. These are, for example, the decision to adopt sustainable development goals at Rio+20; various decisions by the African Ministerial Conference on the Environment; the African Union's Comprehensive Strategy on Climate Change; the African Development Bank's Green Growth Framework; various commitments through the United Nations Framework Convention on Climate Change (UNFCCC) to a low-carbon economy; and other sustainability-oriented priorities; to name but a few.

The growing demand for the transition to the green economy challenges institutions and organisations in the public and private sectors to refine strategies, and associated policy- and decision-making, in and across complex dynamic domains. Some private and public sectors are now pursuing the potential opportunities offered by the green economy; opportunities which, in many cases, are occurring in an ad hoc manner relating to, for example, clean energy and energy efficiency. On the other hand, capabilities and capacities within South Africa to support knowledge-based policy- and decision-making for a green economy transition are limited. This is particularly so with infrastructure. A dramatic transformation of the scope, scale and institutional architecture of these infrastructures will be required, as we cannot rely on incremental changes to our systems.

Good infrastructure management is not solely a technical issue. In particular, the interface between technical and social considerations is poorly understood and inadequately managed at the overall level of the systems. This is especially so in the African context. The challenge for developing a transformative capability of our infrastructures is much broader than what technology and engineering alone can address. We need to fundamentally reconsider how we look at system architectures and processes associated with societal

infrastructures; by learning from the past (and present) with respect to events, behaviours and technology that influence the overall system (see Figure 1). This again emphasises the need for a transdisciplinary approach

(Van Breda et al., 2015) to co-generate knowledge with society so as to establish appropriate management practices of our infrastructure in the transition to a green economy.

Requirements for transdisciplinary research

A new form of research is then required to address the challenge of managing infrastructure appropriately in the context of great uncertainty as we embark on the transitioning to a green economy. This transdisciplinary research should be (Hansman et al., 2006):

- broader than the research that has been traditionally undertaken. The impact of industry and institutional structures, policy, economics and socio-ecological constraints, combined with dispersed decision-making and a myriad of stakeholders call for a systems approach with deep technical and social science perspectives. For example, what was previously treated as context is now part of the design process.
- strengthened by connections with practice. Such relationships should allow knowledge to flow between academia and practice, so that research would be informed by practical realities, while theory supports the effective transition and operation of infrastructures.
- seeking commonality across different infrastructure domains. Looking at similar issues in different contexts stimulates thought and provides significant insights into both fundamental and domain-specific issues.

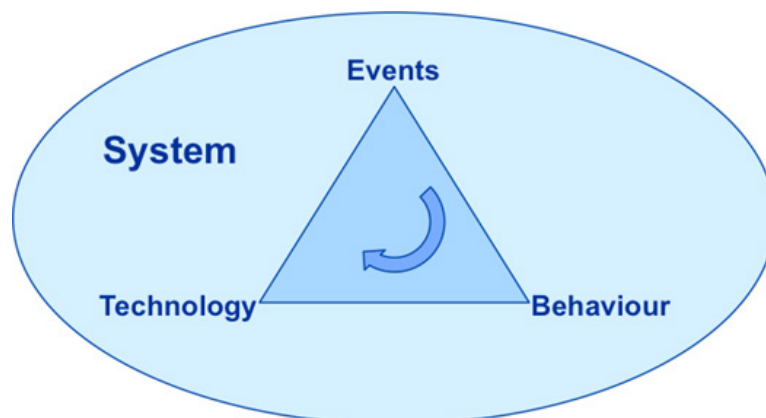


Figure 1. Learning from the past, and the present

(Source: Adapted from Botha, 2015)

The field of technology management

From a domain-specific perspective, technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies in the form of product, process and infrastructure. These are needed to sustain the competitive advantage of regional sectors in accordance with sector, regional, national and international sustainable development objectives. The technology management process is conceptualised in

Figure 2. The details are provided elsewhere (Brent and Pretorius, 2008a; Brent, 2012).

Technology management commences with idea generations: ideas enter the wide end of a funnel and are then screened along the funnel through scientific and engineering performance criteria with the objective of identifying, selecting and economically exploiting innovations. The first screening phase of the funnel, namely pre-feasibility and feasibility, occurs through a formal research and development (R&D) life cycle with idea,

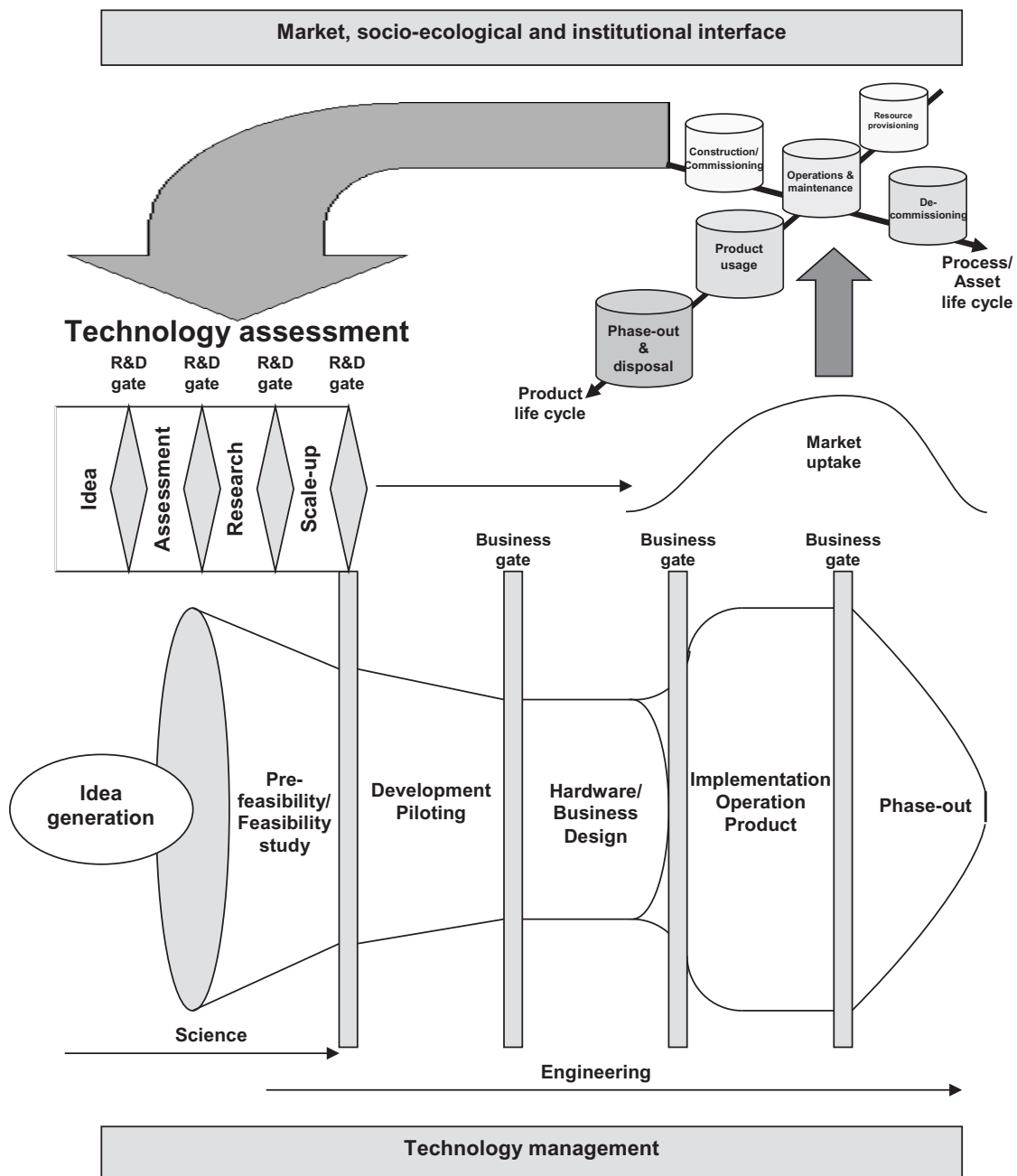


Figure 2. Technology life-cycle interventions and associated evaluated systems
(Source: Brent and Pretorius, 2008a; Brent, 2012)

assessment, research and scale-up phases and associated decision gates, which are typical of R&D institutions. The final R&D decision is to commence, or not, with the development, implementation and exploitation (DIE) of the R&D output. Many tools and methods are applied in the DIE phases to support business-oriented decision gates to optimise and maximise the return on innovations. Through the market-uptake cycle, many different technology life cycles are associated with the innovation; that is, the life cycles of process and physical assets that manufacture or produce products and/or services and the life cycles of the products and/or services themselves. A holistic understanding of the sustainable development implications during the market-uptake cycle of innovations is required during the pre-feasibility and feasibility phases of the technology life cycle. Bringing practical solutions to sustainable development problems then requires a transdisciplinary knowledge base and a holistic management approach (Klein, 2004). Therefore, during these phases, adaptations of conventional

technology assessment approaches (Pretorius and de Wet, 2000) are necessary and a number of statements have been made with regard to the ongoing development of relevant performance metrics that relate to socio-ecological systems (Geisler, 2002):

- Technology is not judged by its existence alone, nor is its mere existence a sufficient condition for successful usage.
- We cannot evaluate technology unless and until we put it in the context of social (and environmental) and economic phenomena.
- Technology is not defined and evaluated by what it is but by the criteria outside itself – by its actual and potential users.

From a sustainability perspective, it is, then, necessary to understand technology as embedded in a larger system (see Figure 3). Future projections need to be made as to how the technology may interact with other sub-systems.

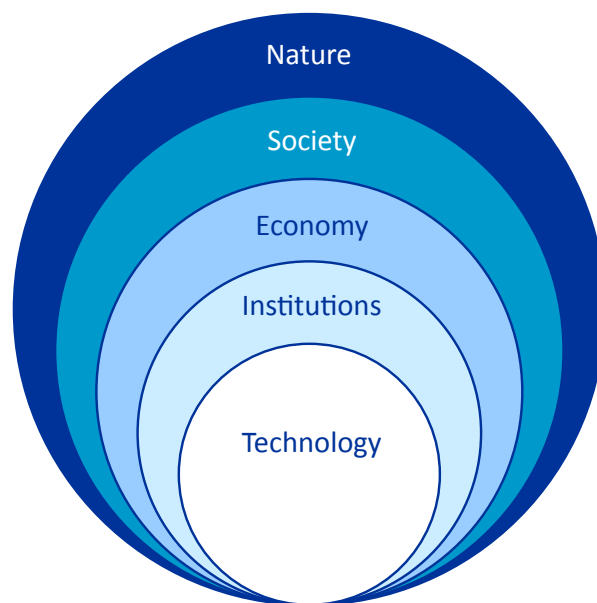


Figure 3. Technology as embedded in the larger system of consideration

(Source: Brent, 2012)

Requirements for a systems approach

Following these requirements for a new form of research, and a systems perspective to technology sustainability, an emerging literature is investigating various aspects of green economy transitioning. Tran (2014) argues that there is still considerable scope to develop new, and use existing tools and techniques, to improve our understanding of socio-technical transitions. There has been parallel works from disciplines such as industrial economics, sociology, political science and

cultural studies. However, Geels (2004) urges that further cross-overs between disciplines are needed to improve the understanding and insight into the dynamics of socio-technical transitions and how such transitions can be fostered, influenced and possibly even managed. For example, Doval and Negulescu (2014) used a survey to establish a model on the implications of green investments particularly for technology and the business sector. The key implications that they found were: (i) the formation of a new market; (ii) the stability of

small to medium enterprises; (iii) and the development of new policies targeting low-carbon transition in order to maximise the value of green investments.

The study by Musango, Brent and Bassi (2014) is noteworthy in that it was the first in South Africa to develop an integrated system dynamics model to examine the transition to a green economy. They showed that green economy interventions could result in a low-carbon transition, could utilise resources efficiently and could create additional jobs without necessarily slowing the economy. In addition, Musango, Brent and Bassi (2014) specifically examined the green economy transition of the electricity sector in South Africa based on the South African green economy model. However, the limitation of the studies of Musango, Brent and Bassi (2014) and Musango, Brent and Tshangela (2014) is that the analyses were undertaken at a national level; yet, many of the green economy investment interventions pertaining to infrastructure and associated technology are taking place at provincial and local government levels. Further, the decision-makers of the provincial and local governments are interested in understanding how much investment would be required to reach their planned targets, or whether their planned investments would achieve their planned targets.

Objective of the paper

This paper, then, aims to improve our understanding, of how technical, economic, political and other socio-ecological factors interact, and to develop the associated capacities and capabilities, particularly in the context of great uncertainties as we embark on the transition to a green economy. In this way specifically the practice of technology management may be improved. The focus, then, is on analysing future trends in infrastructure and technology development to enable the socio-technical transition to a green economy. The paper thus follows a similar conceptual framework to the one used for the South Africa Green Economy Model (SAGEM), which was developed (DEA and UNEP, 2013; Musango, Brent and Bassi, 2014; Musango, Brent and Tshangela, 2014) to investigate the implications of green economy investments in the Western Cape Province of South Africa; as a case study. The paper finally provides insights of future developments, and what this might entail for the field of technology management.

UTILISING THE SYSTEM DYNAMICS MODELLING APPROACH

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

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

According to Cavana and Maani (2000), there exist five major phases in the development of a systems thinking and modelling intervention: (1) problem structuring, (2) causal loop modelling, (3) dynamic modelling, (4) scenario planning, and (5) implementation and organisational learning (see Figure 4). From a modelling perspective, system dynamics makes use of four basic building blocks, namely stocks, flows, auxiliaries and constants (Musango, Brent and Tshangela, 2014). Using these basic building blocks, it is possible to capture dynamic complexity and represent different viewpoints. This is very relevant when it comes to green economy issues that require accounting for economy, society and environment sub-systems (see Figure 5). Further, it is possible to develop scenarios in order to test the implications of green economy interventions.

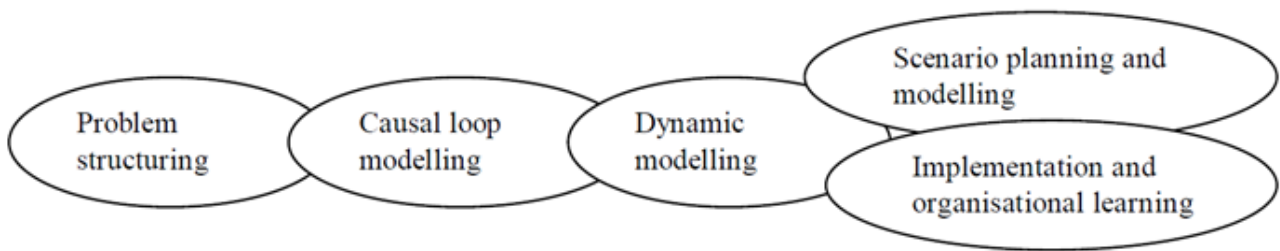


Figure 4. Five phases of the systems thinking and modelling methodology
(Source: Cavana and Maani, 2000)

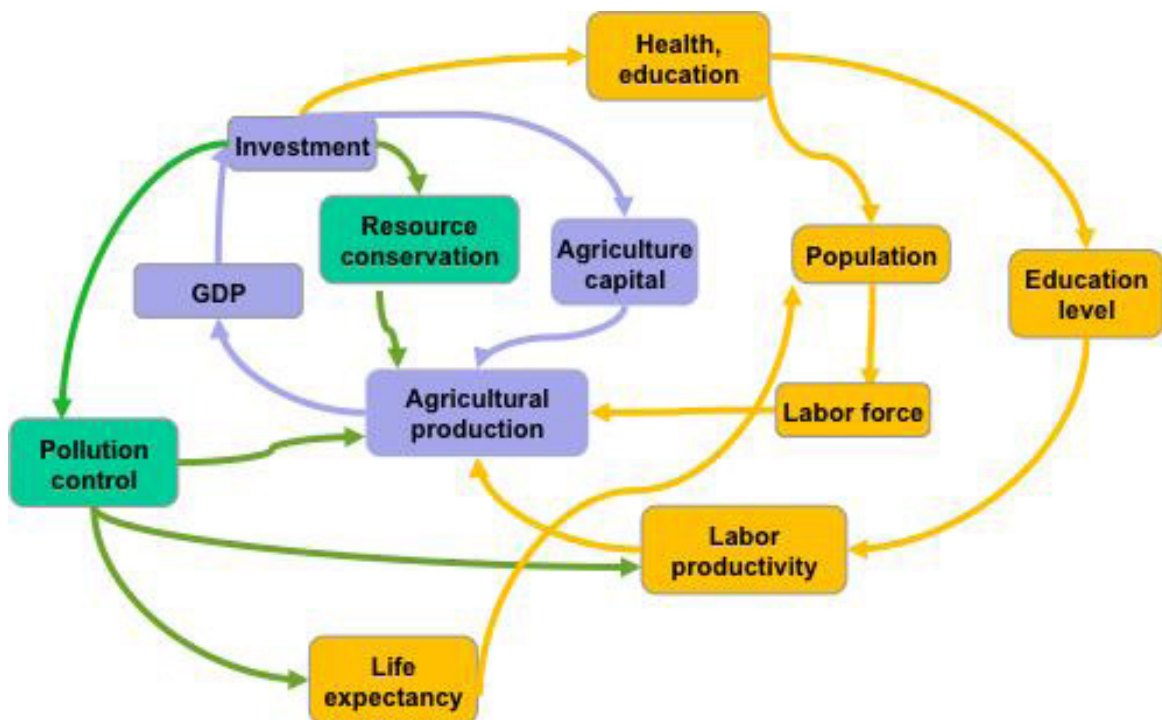


Figure 5. A simplification of how system dynamics enables the identification of the relationship between issues
(Source: DEA and UNEP, 2013)

THE WESTERN CAPE PROVINCE AS A CASE STUDY

The Western Cape Province is the fourth largest of the nine provinces in South Africa, both in terms of area and in terms of population. It covers an area of 129 370 km² and is home to just over 6 million people (STATS SA, 2014).

The central emphasis of the transition to a green economy in the Western Cape Province primarily arises from the national policy response to the National Climate Change Response White Paper (DEA, 2011). The strategic priorities outlined in this document provide the direction of action and responsibility for the different

levels of government. Section 10.2.6 of the National Climate Change Response states that: “Each province will develop a climate response strategy, which evaluates provincial climate risks and impacts and seeks to give effect to the National Climate Change Response Policy at provincial level” (DEA, 2011). In response to this, the provincial government created the Western Cape Green Economy Strategy Framework with growth in green investments and market opportunities at the core of the strategic framework (Western Cape Government, 2013). According to the Strategy, the Western Cape Province aims at positioning itself as the lowest carbon province in South Africa and the leading green economic hub of the African continent. Five drivers that are

identified for transitioning to a green economy are as follows (Western Cape Government, 2013):

- Smart living and working: creating opportunities through less resource-intensive living and working environments and consumption patterns.
- Smart mobility: investment, job and enterprise opportunities created through reduced resource intensity of mobility and smarter mobility systems.
- Smart ecosystem: enhanced water and biodiversity preservation, and expanded infrastructure, tourism, livelihood and job opportunities created through better managed ecosystems.
- Smart agri-production: livelihood and market opportunities created through enhancing the competitiveness and resilience of our agricultural and food economies.
- Smart enterprise: investment, business and job opportunities created by establishing the Western Cape as a globally recognised centre of green living, working, creativity, business and investment.

While the Strategy may point towards transitioning, it remains the responsibility of the municipalities to plan and respond to climate change amidst the demanding challenges they have to deal with. These challenges include, among others, limited skills 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 adaptations for future conditions (South Africa LED Network, 2010). All of which form the setting of the emerging need to prepare municipalities towards a green economic transition.

Informed by the Strategy, this paper specifically focuses, from a carbon reduction perspective, on transport, agriculture, and (renewable) energy infra-

structure and technologies, while water resources and public services are considered as a starting point for the investigation. The details of the modelling, and the analyses of scenarios up to 2040, are described elsewhere (Musango et al., 2015, York et al., 2015; Van Niekerk et al., 2015; Oosthuizen and Brent, 2015).

OUTCOMES OF THE MODELLING AND ANALYSES

A number of scenarios were analysed (Musango et al., 2015, York et al., 2015; Van Niekerk et al., 2015; Oosthuizen and Brent, 2015) for the various sectors and technologies considered for the green economy transition in the Western Cape Province. Some of the outcomes are summarised here.

Transportation transitions

For the transportation infrastructure the following were considered (York et al., 2015):

- The business-as-usual (BAU) scenario, which considers current policies and action plans or strategies in the Province.
- S1: Green economy investment into public passenger transport.
- S2: Green economy investment into the freight rail system.
- S3: Green economy investment into both.

While targeted investments in this sector could reduce the carbon emissions of the Province by 17% (see Figure 6), with a minor reduction in fuel demand (see Figure 7) and other benefits such as employment, the investment would be substantial; in the order of 50% more than the BAU scenario for all the green economy scenarios (see Figure 8). However, to put this into perspective, the investment is in the order of 1% of GDP by 2040.

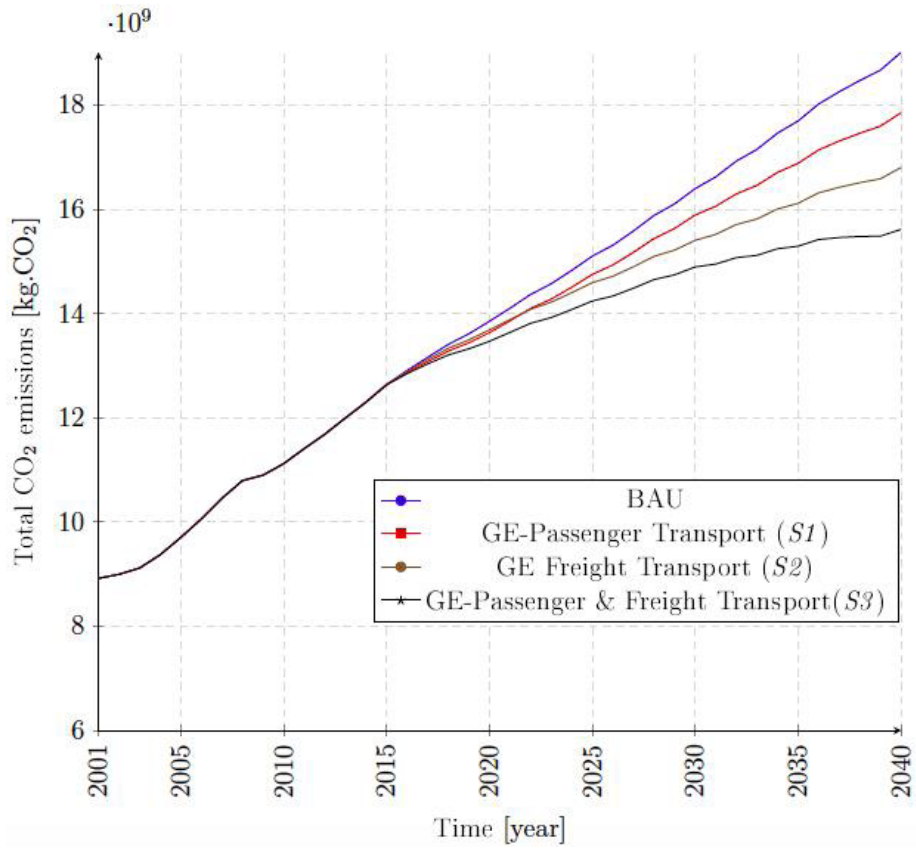


Figure 6. Carbon reductions from the various transportation scenarios
 (Source: York et al., 2015)

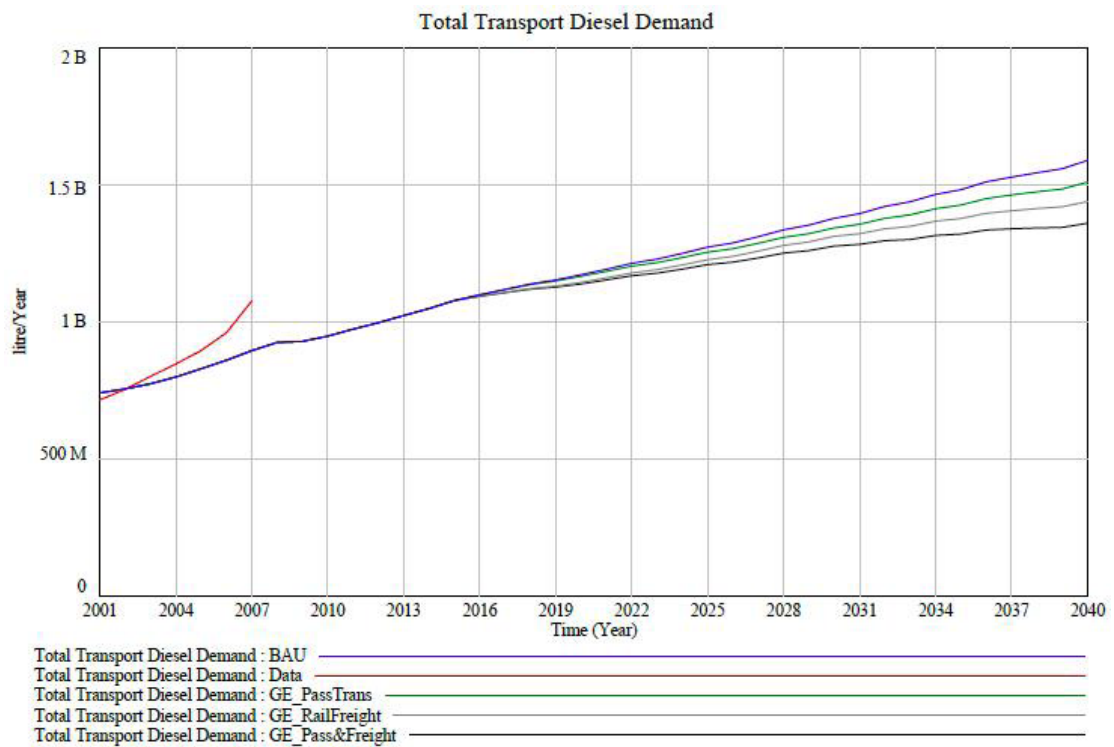


Figure 7. Fuel demand reductions from the various transportation scenarios
 (Source: York et al., 2015)

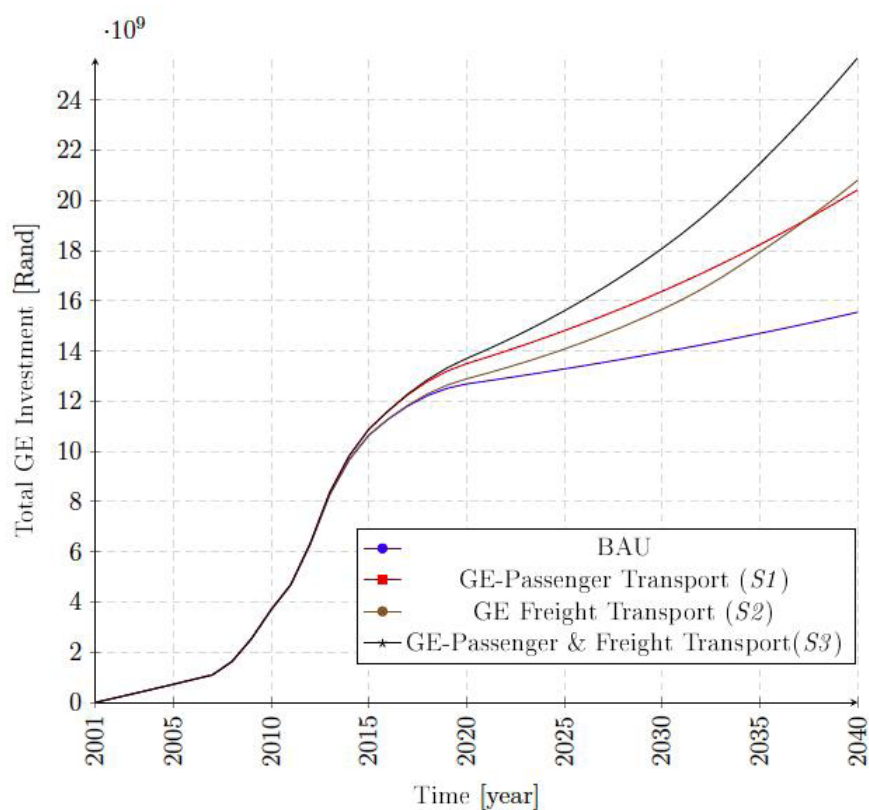


Figure 8. Investment requirements for the various transportation scenarios

(Source: York et al., 2015)

Agriculture transitions

For the agriculture sector, a number of scenarios were derived, based on the increasing emphasis on organic and conservation farming (see Table I).

Table I. Scenarios to transition the agriculture sector

Input parameters	Model scenarios			
	BAU	GR BC	GR WC	GR RC
Organic yield	75%	100%	65%	75%
Conservation yield	110%	110%	110%	110%
Conventional area	80%	45%	45%	45%
Organic area	5%	15%	15%	15%
Conservation area	15%	40%	40%	40%

(Source: Van Niekerk et al., 2015)

The associated carbon reduction achievements are minimal (see Figure 9), as are other environmental benefits such as land use (see Figure 10) and changes in employment opportunities. The investment requirements, however, are (potentially) three-fold (see Figure 11); albeit around 0.5% of GDP by 2040.

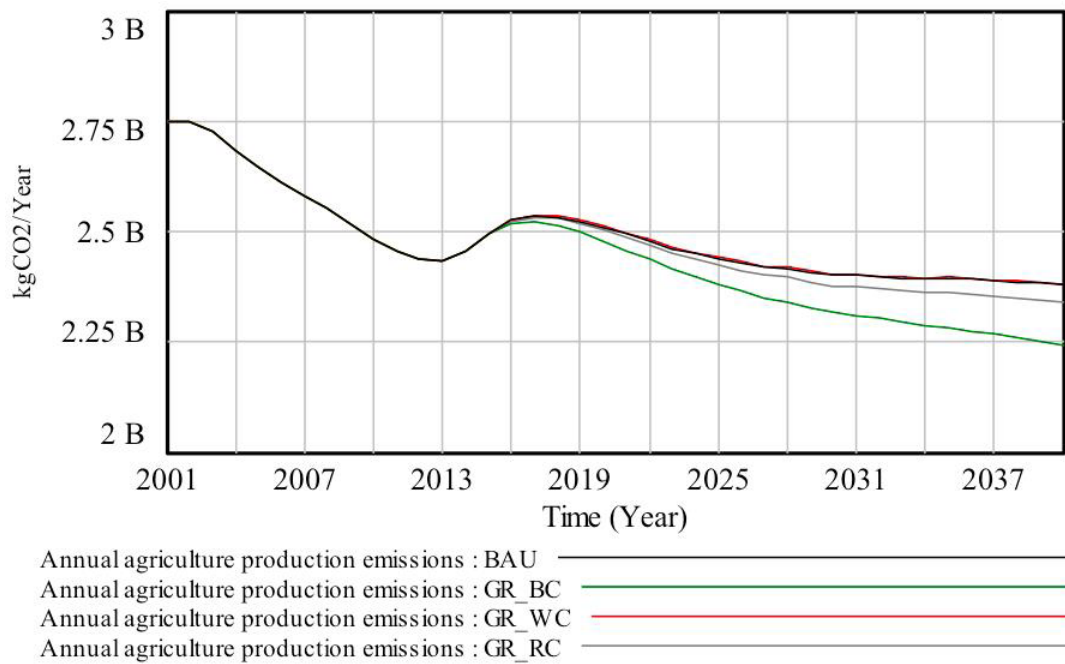


Figure 9. Carbon reductions from the various agricultural scenarios
 (Source: Van Niekerk et al., 2015)

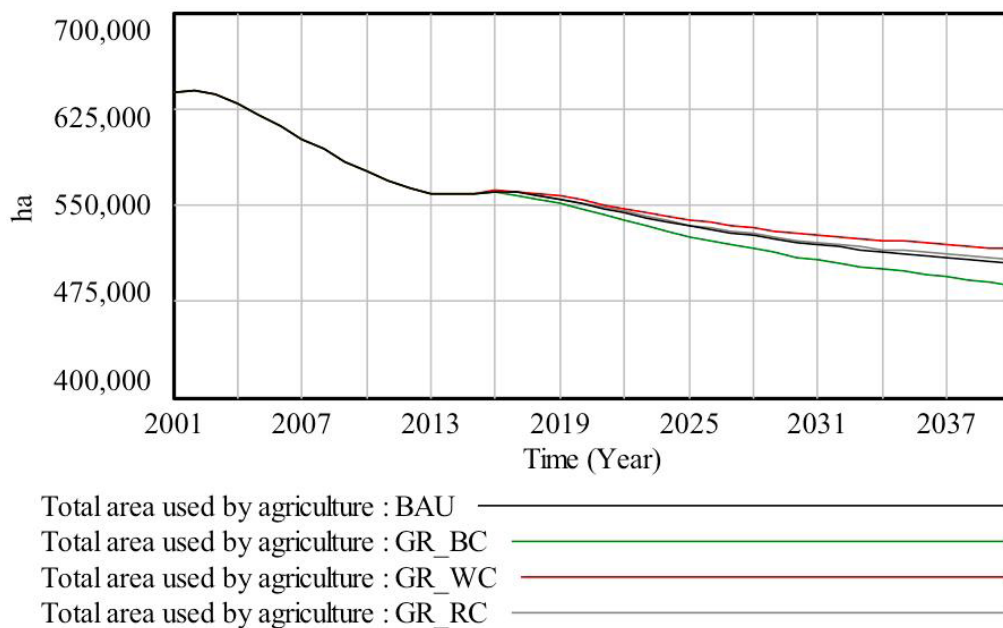


Figure 10. Land requirement of the various agricultural scenarios
 (Source: Van Niekerk et al., 2015)

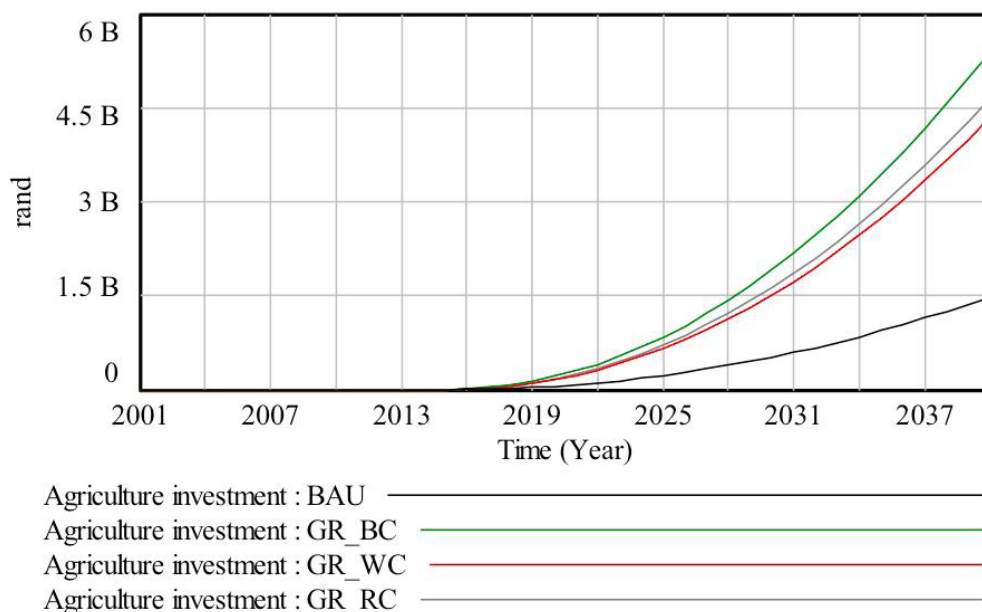


Figure 11. Investment requirements of the various agricultural scenarios
 (Source: Van Niekerk et al., 2015)

Energy transitions

Two main categories of scenario were investigated for the electricity sector (Oosthuizen and Brent, 2015). The first category was business-as-usual (BAU), which assumes a continuation of the current electricity sector investment policies and regulations until 2040. This translates to a minimum investment in renewable energies and gas, and a continuation of importing a significant share of electricity from outside the Province's borders. BAU acts as the baseline against which future green investment scenarios can be compared.

The second category was green economy investment (GEI), which assumes that active government intervention assures that allocated investments are made in certain cleaner electricity technologies. This category assures an annual investment of 1% of GDP in cleaner electricity technologies according to two scenarios. (The figure of 1% of GDP was decided upon because it is a realistic figure from an economic perspective; it is a figure that can be pursued by the provincial government without being overambitious. At the same time, this figure is perceived to be large enough to make an impact on the electricity sector. It is also in the same order of magnitude as the investment requirement identified in the transportation and agricultural sectors.) The first scenario (GEI RE) simulates a policy where investments are only made in

wind and solar photovoltaic capacity. The second GEI scenario (GEI RE+G) simulates a policy where gas power generation is used as a transition technology towards a renewable energy future. In GEI RE+G, investments are concentrated towards gas power generation from 2015 to 2019, after which investments are concentrated on renewable energy technologies. The three scenarios are only implemented in 2015, with BAU being the default scenario between 2001 and 2014.

The two main priorities for investment in the electricity sector are matching electricity supply with electricity demand, and increasing the share of cleaner electricity technologies. Figure 12 shows the demand-supply gap for the three scenarios that were simulated. Only the two GEI policies manage to decrease the demand-supply gap, with the BAU policy not being able to add enough capacity to the electricity grid. The gap in the BAU scenario is almost five times larger than for the two GEI scenarios by 2040. The GEI RE+G policy is the most effective, indicating that the combination of gas power and renewable energy will be most effective in reducing the gap between demand and supply. Gas power is slightly cheaper than renewable power; therefore an investment in gas power capacity will offer greater electricity supply than an investment in renewable energy.

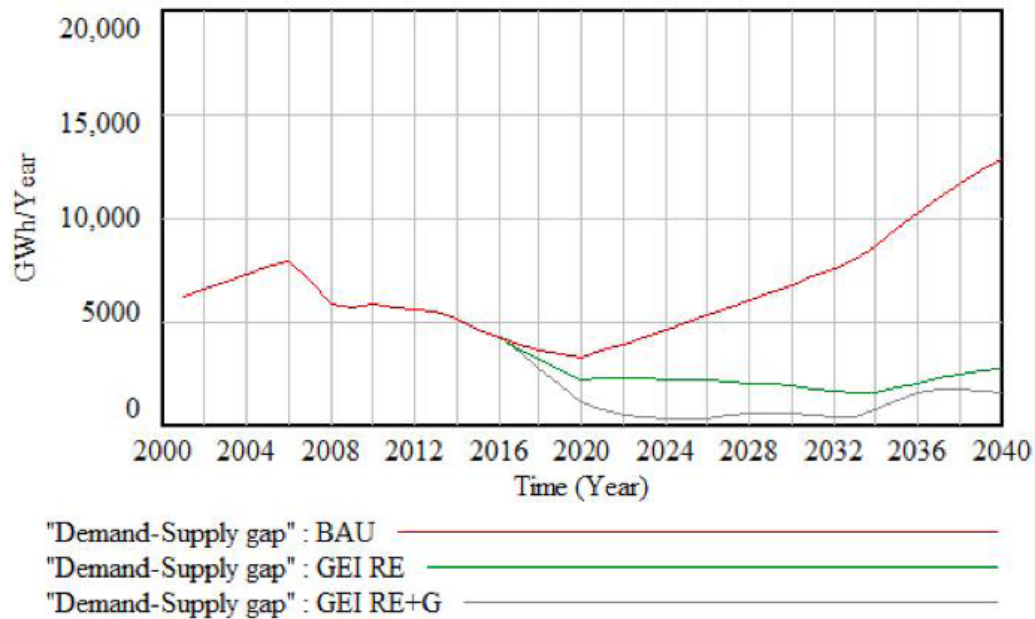


Figure 12. Demand-supply gap analysis for the three scenarios
 (Source: Oosthuizen and Brent, 2015)

Figure 13 shows the share of electricity consumption from renewable energy technologies. The GEI RE policy reaches a peak renewable energy share of 42%. The GEI RE+G policy reaches a share of 34%, with the BAU policy only reaching a peak share of 14%. The BAU scenario consequently sees much greater CO₂ emissions because electricity must be imported at an increasing rate (see Figure 14). This electricity comes from coal-based power technologies that are carbon intensive. The two GEI scenarios manage to reduce carbon emissions from their 2014 levels, but the fact that they still include supply from imported coal power and gas power means that air emissions cannot decrease significantly. However, it does stabilise the emissions of the electricity sector in the Province. By 2040, the carbon emissions under the BAU scenario are more than double those for the GEI scenarios.

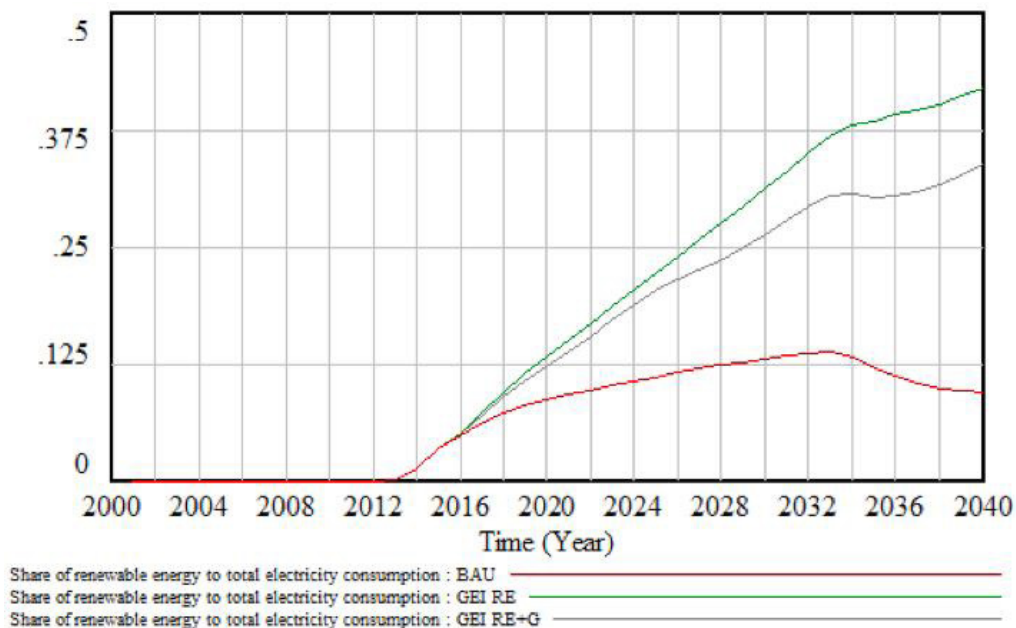


Figure 13. Share of renewable energy for the three scenarios
 (Source: Oosthuizen and Brent, 2015)

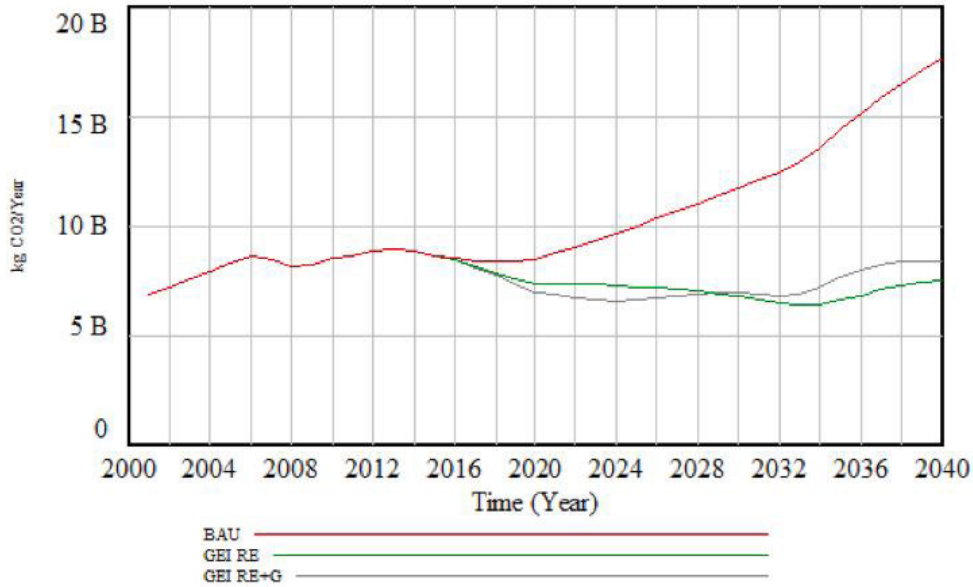


Figure 14. Carbon emissions for the three modeled scenarios

(Source: Oosthuizen and Brent, 2015)

A major implication of investing in the energy infrastructure transition, as opposed to the other two sectors, is that of employment; a key issue in the South African context. Both GEI policies are successful in achieving growth in power sector employment, with close to 14 000 people being employed in the power sector by 2040 for both GEI scenarios. The BAU scenario offers very limited growth in employment due to the lack of investment in the sector (see Figure 15). The initial peak in employment before 2010 is due to the construction of the Ankerlig and Gourikwa open cycle gas turbine (OCGT) power stations.

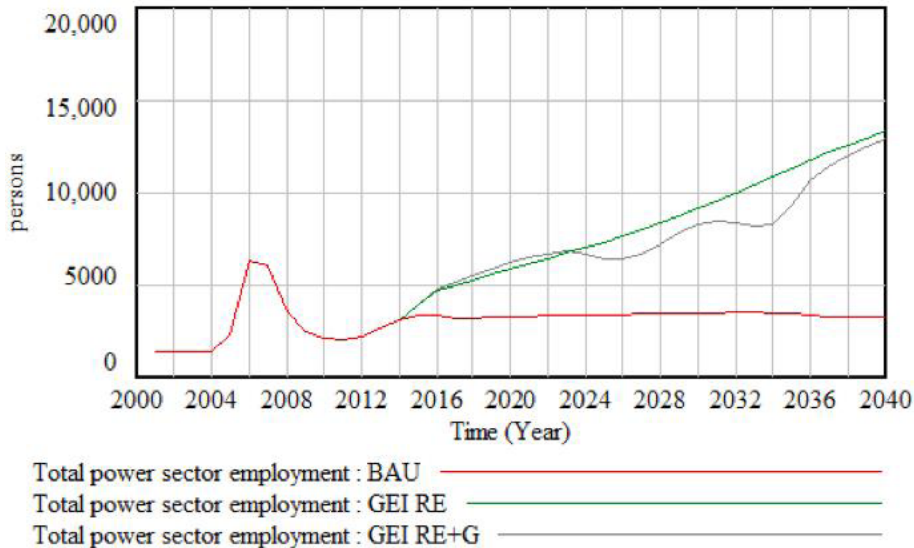


Figure 15. Total employment created in the energy sector for the three scenarios

(Source: Oosthuizen and Brent, 2015)

DISCUSSION: IMPLICATIONS FOR TECHNOLOGY MANAGEMENT

These transition scenario analyses demonstrate a high variability in the future of technology development, since the infrastructure scenarios are highly dependent on investment decisions in the public, and subsequently the private, sector. Also, the development and diffusion of the associated technologies that contribute towards addressing the sustainability challenges (both environmental and developmental) are deemed one of the main pathways towards sustainable futures (Paredis, 2011). However, transitioning to sustainable socio-technical systems depends on both technological and far-reaching behavioural innovations (Tran, 2014) that are unique and cannot develop without fundamentally rethinking economic and wider societal conditions (Wagner et al., 2014). This is demonstrated through the intricate, and dynamic, sub-system models that underpin the scenario analyses for the Western Cape case study; many with parameters that are hard, if not impossible, to quantify.

Geels (2002) states that “technology, of itself, has no power, does nothing”. This argument holds that only in conjunction with society, institutions, governing bodies and organisations can technological innovation fulfil its function. It is also this interaction between, and mixture of, the social and technological aspects of a system that are of interest (Geels 2002). From the perspective of sustainable development, Tran (2014) argues that in order to transition to sustainability, large-scale technological and behavioural innovation diffusion is required. And it is this, the diffusion of technological innovations, and specifically the diffusion of nexus technologies¹, alongside the required social innovations, that will bring about the transition to a sustainable socio-technical system. Thus understanding the dynamics and complexities surrounding technological change is important when aiming to govern socio-technical transitions and manage technologies into the future.

The uncertainties that are inherent with green economy transitions mean that, increasingly, the importance of systems thinking in technology management practices is recognised. Indeed, McCarthy (2003) suggests a complex adaptive systems approach that views organisations as evolving systems that formulate strategies by classifying, selecting, adopting

and exploiting various combinations of technological capabilities in response to the market. However, these types of approaches still tend to be inwardly focussed. Brent and Pretorius (2008b) and Brent (2012) highlight the importance of an outward focus for the field of technology management, in order to analyse and understand the sustainability of technologies in context. They argue for the need to incorporate the principles of sustainability science (Kates et al., 2001) into technology management practices (see Figure 16), specifically to establish appropriate performance metrics for technologies with stakeholders in society, in a transdisciplinary way (see Table 2).

With regard to developing countries, especially, Lachman (2013) argues that the approaches that have been developed to study socio-technical transitions are heavily flavoured by the context of developed countries – the environment within which they were developed – and thus might be less suitable for contexts such as that of developing countries. In addition, Tigabu et al. (2013) argue that most research concerned with transitions was conducted in highly developed countries, and the applicability of these theories and approaches to developing countries is still unclear. There is thus a need to establish the applicability and suitability of the developed approaches and frameworks to study socio-technical transitions within the context of developing countries, particularly with regard to nexus technologies (De Kock, 2015).

¹ De Kock (2015) conceptually defines ‘nexus technologies’ as technologies that consist of a set of individually developed technologies, each on their own developmental curve, with varying technology maturity levels and learning rates, configured together to form a nexus technology. The green or sustainability-oriented technologies that have emerged, and will emerge into the future, especially hold structural characteristics that are new, or different from, traditional technologies.

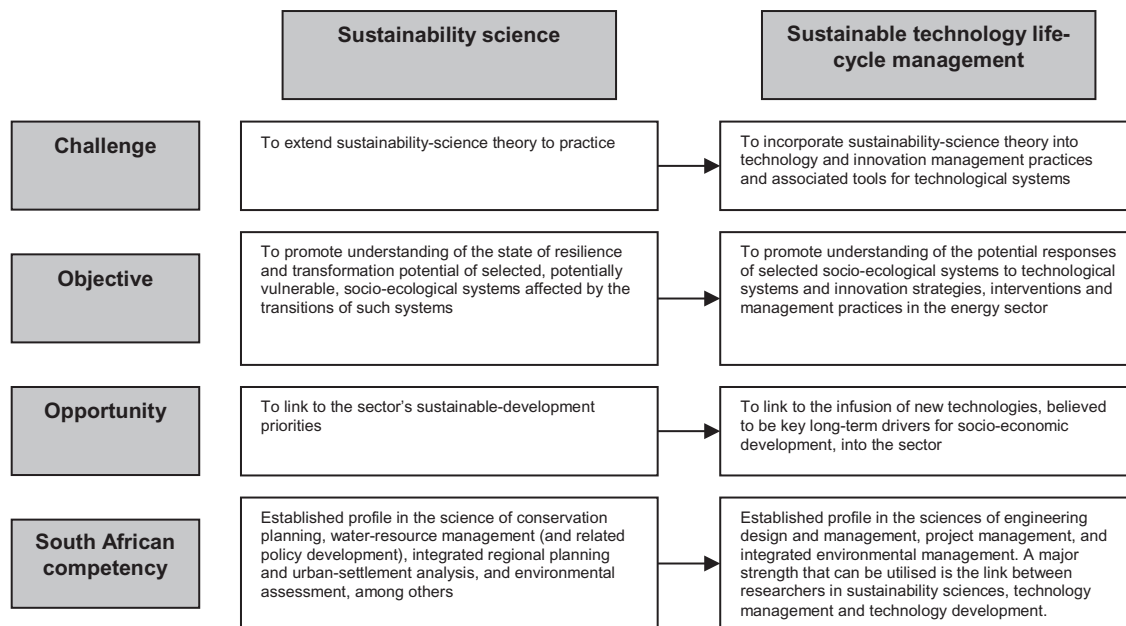


Figure 16. Extension of the sustainability science field to technology management

(Source: Brent, 2012)

Table 2. Specific theories of sustainability science relating to performance metrics for technological systems

Theory	In the context of sustainability science	In the context of the performance metrics of technologies
Transdisciplinarity	The result of a coordination of disciplines, such as science and the laws of nature, technology and what is achievable, law and politics and what is acceptable to social systems, and the ethics of what is right and wrong beyond the bounds of society.	Where successful transformation of technologies into marketable commodities requires knowledge and skills from a variety of different specialist fields of science and engineering.
Resilience	A system's ability to bounce back to a reference state after a disturbance and capacity to maintain characteristic structures and functions despite the disturbance. Where ecological resilience is the amount of disturbance that a system can absorb before it changes state. Ecological resilience is based on the demonstrated property of alternative stable states in ecological systems. Engineering resilience implies only one stable state (and global equilibrium). Further, a resilient ecosystem can withstand shocks and rebuilds itself when necessary. Resilience in social systems has the added capacity of humans to anticipate and plan for the future. Resilience is conferred in human and ecological systems by adaptive capacity.	The resistance and robustness of an integrated system against surprises, which includes risk-based measures and precautionary regulations and the capacity to buffer change, learn and develop.
Complexity	From a biology perspective, the understanding of how the parts of a biological system – genes or molecules – interact is just as important as understanding the parts themselves". From a natural-systems perspective, complex interactions of natural systems that are not chaotic. Furthermore, the growing appreciation of the need to work with affected stakeholders to understand the full range of aspects of any particular system.	Deals with the study of complex systems, i.e. composed of many interacting elements that interact in complex ways, and the ability to model complex interaction structures with few parameters.
Adaptive management	Adaptive resource management is an iterative process of optimal decision-making in the face of uncertainty, with the aim to reduce that uncertainty over time via system monitoring.	
Adaptive capacity	As applied to human social systems, the adaptive capacity is determined by: <ul style="list-style-type: none"> The ability of institutions and networks to learn, and store knowledge and experience. Creative flexibility in decision-making and problem solving. The existence of power structures that are responsive and consider the needs of all stakeholders. Adaptive capacity is associated with selection strategies in ecology and with a movement from explosive positive feedback to sustainable negative feedback loops in social systems and technologies.	

(Source: Brent, 2012)

CONCLUSIONS

The world is a changing place with major challenges that define our era and civilisation. Some of these challenges are deemed crises; for example, poverty, inequality and resource depletion. However, it is recognised that these crises are interconnected and that they cannot be understood, and solved, individually. Rather a polycrisis ‘lens’ is required that recognises the nexuses between elements and actors of a larger system. These nexuses define the trajectory or pathway of our civilisation. Figure 17 illustrates the water-energy nexus as an example.

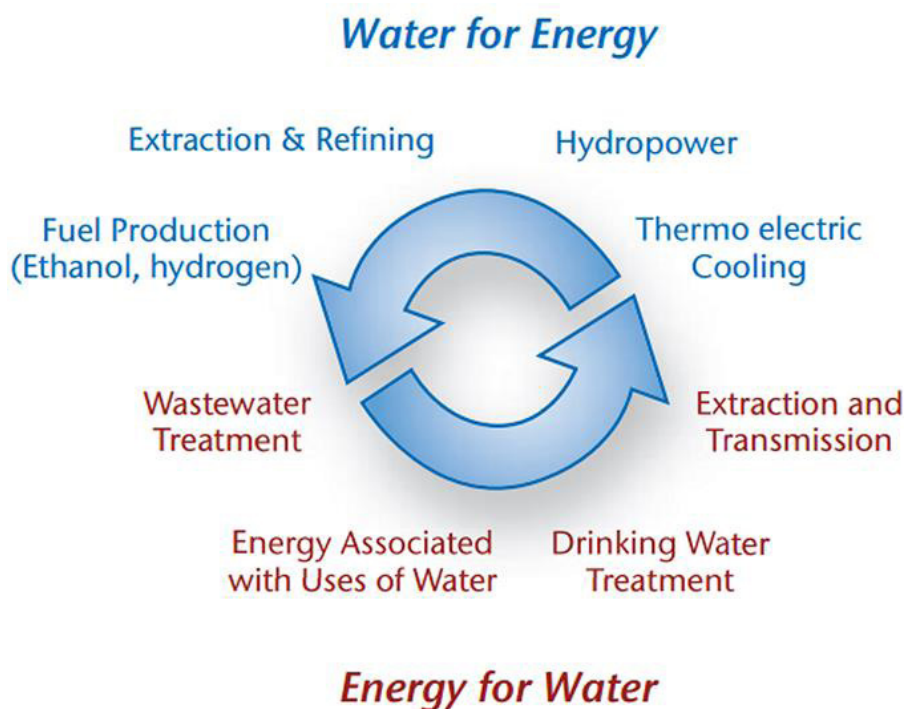


Figure 17. The water-energy nexus

(Source: World Business Council for Sustainable Development, 2009)

Climate change has been termed a ‘megaforce’ (KPMG, 2012) that directly impacts, and interacts with, all other challenges, such as (affordable) energy and fuel, material resource scarcity, water scarcity, population growth, urbanisation, wealth, food security, ecosystem decline and deforestation. A response has been the green economy movement (UNEP, 2011), which has seen a significant uptake in the public sector, with the private sector responding accordingly. To this end the South African government calls for a transition to a low-carbon, resilient economy (DEA and UNEP, 2013) – as it defines the green economy. Such a transition comes with its own challenges, one being the ability to forecast the implications of such a transition through a systems approach.

This paper has used the Western Cape Province of South Africa as a case study to investigate potential scenarios pertaining to investment interventions in the transportation, agricultural and energy sectors, based on system dynamics modelling. The transition scenario analyses demonstrate a high variability in the future of technology development, with consequences for the practice of technology management. Apart from the uncertainty of policy, and investment, trajectories, there is the uncertainty of the system context for technologies – for sustainable futures – which is of even greater importance. This, then, calls for a greater emphasis on transdisciplinarity, in order to understand the contexts better for technologies and innovations. This challenge to an organisation can also be seen as an opportunity, in what KPMG (2012) refers to as the innovation nexus: “the opportunity to address sustainability challenges through business innovation” – by driving innovation together with society.

In the developing-country context, especially, there is a need to develop approaches and frameworks to enable socio-technical transitions, and to establish management methods, particularly with regard to nexus technologies (De Kock, 2015), that will play a vital role as we embark on a pathway to sustainable futures.

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