

The Transition To A Green Economy

A Systems Approach To Managing Technology

Alan C Brent

Department of Industrial Engineering, and the
Centre for Renewable and Sustainable Energy
Studies (CRSES)

Stellenbosch University

Stellenbosch, South Africa
acb@sun.ac.za

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 of South Africa 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

I.

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 [1] 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 [2], 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 improvements. However, many infrastructures have been difficult to transform effectively and efficiently. Hansman, Magee, de Neufville, Robins, and Roos [3] 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 [4]: 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 [5] to co-generate knowledge with society so as to establish appropriate management practices of our infrastructure in the transition to a green economy.

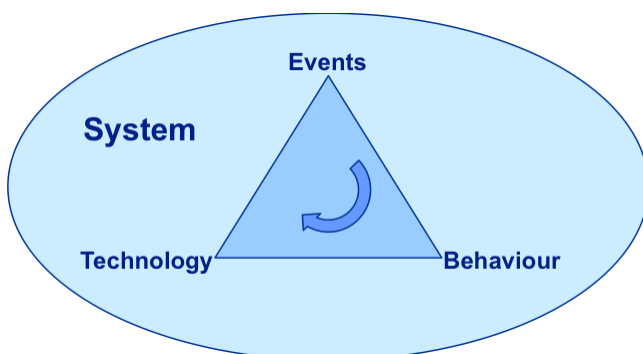


Fig. 1. Learning from the past, and the present

(Source: Adapted from Botha [6])

A. Requirement 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 [7]:

- 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.

B. 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 [8, 9].

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, 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.

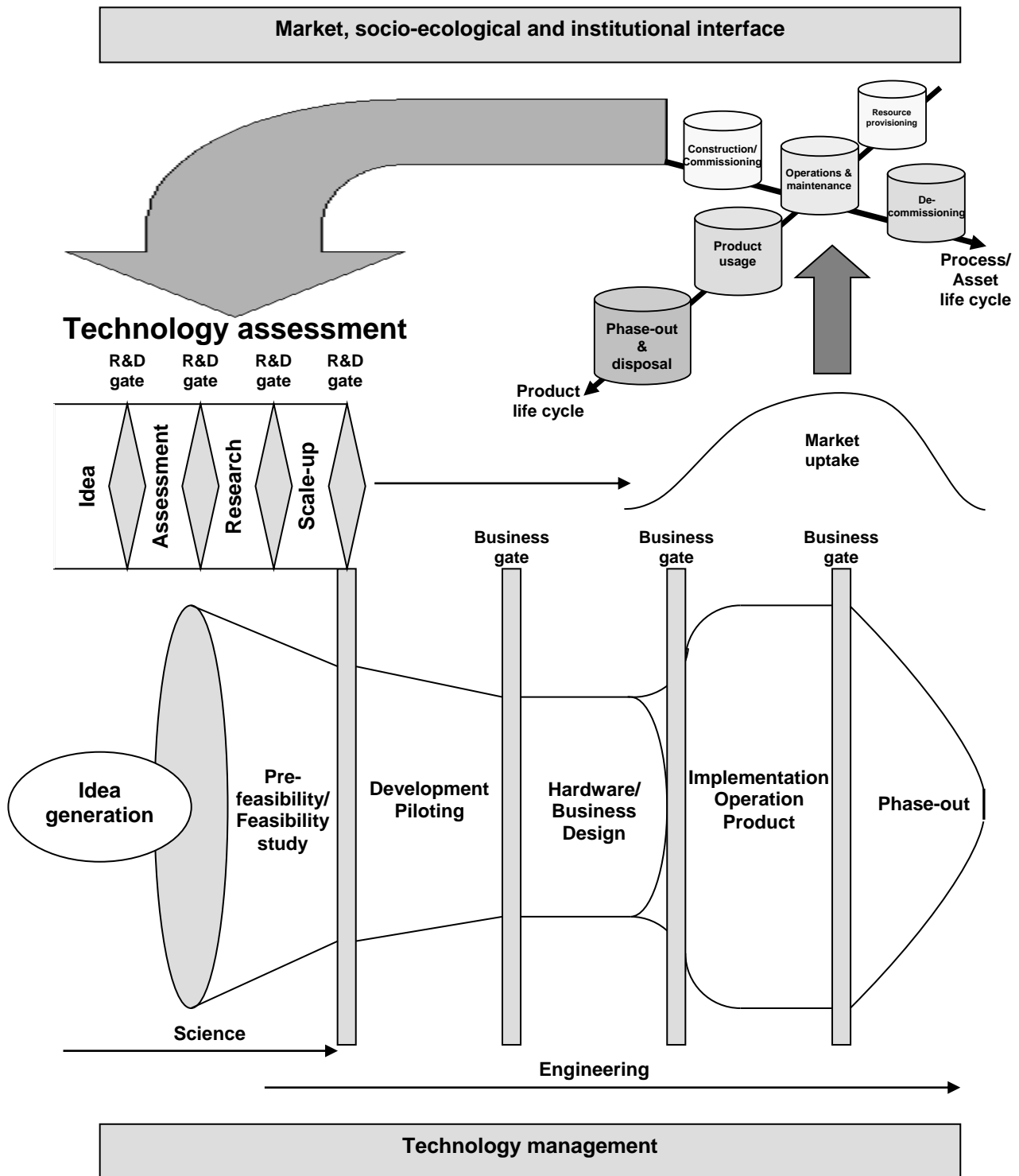


Fig. 2. Technology life-cycle interventions and associated evaluated systems

(Source: Brent [9])

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 [10]. Therefore, during these phases, adaptations of conventional technology assessment approaches [11] are necessary.

A number of statements have then been made with regard to the ongoing development of relevant performance metrics that relate to socio-ecological systems [12]:

- 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.

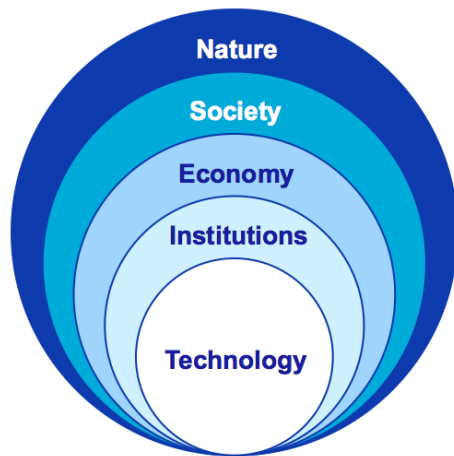


Fig. 3. *Technology as embedded in the larger system of consideration*

(Source: Brent [9])

C. 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 [13] 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 [14] 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 [15] 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 [16] 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 Tshangela [17] 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 these studies [16, 17] 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.

D. 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 [4, 16, 17] 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.

II. 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 [18, 19].

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 [20] developed system dynamics in the 1950s when he first applied it to analyse industrial business cycles. Since then system dynamics has been applied to address problems from various fields of study relating to economy, society and environment. For instance, Ford [21] illustrates cases for the application of system dynamics in modelling environmental issues. Forrester [22, 23] applied it in analysing socio-economic dynamics. Several authors have utilised it in sustainability issues including, among others, water resource management [24], energy planning [25, 26], urban planning [27] and climate change mitigation [28]. Systems dynamics is also being used to investigate issues relating to a green economy transition [1, 16, 17].

According to Cavana and Maani [29], 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 [17]. 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.

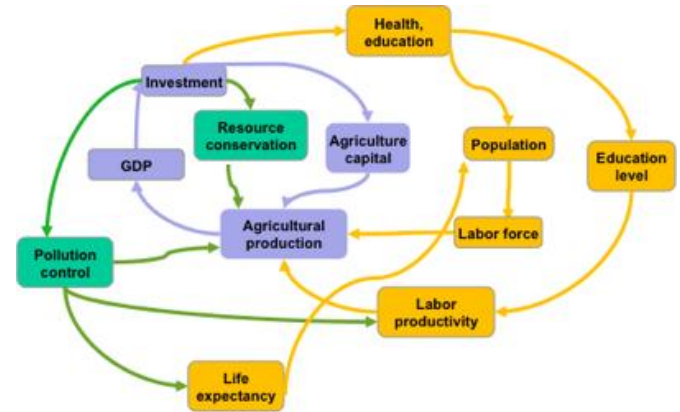


Fig. 5. A simplification of how system dynamics enables the identification of the relationship between issues

(Source: DEA and UNEP [4])

III. 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 [30].

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 [31]. 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" [31]. 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 [32]. 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 [32]:

- 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.

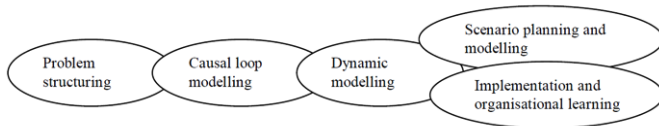


Fig. 4. Five phases of the systems thinking and modelling methodology

(Source: Cavana and Maani [29])

- 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 [33]. 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 infrastructure 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 [34, 35, 36, 37].

IV. OUTCOMES OF THE MODELLING AND ANALYSES

A number of scenarios were analysed for the various sectors and technologies considered for the green economy transition in the Western Cape Province [34, 35, 36, 37]. Some of the outcomes are summarised here.

A. Transportation transitions

For the transportation infrastructure the following were considered [35]:

- 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.

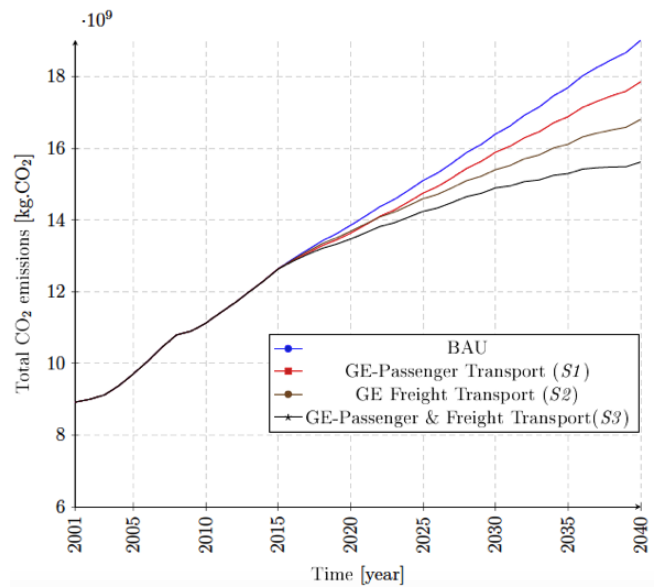


Fig. 6. Carbon reductions from the various transportation scenarios

(Source: York, Brent, and Musango [35])

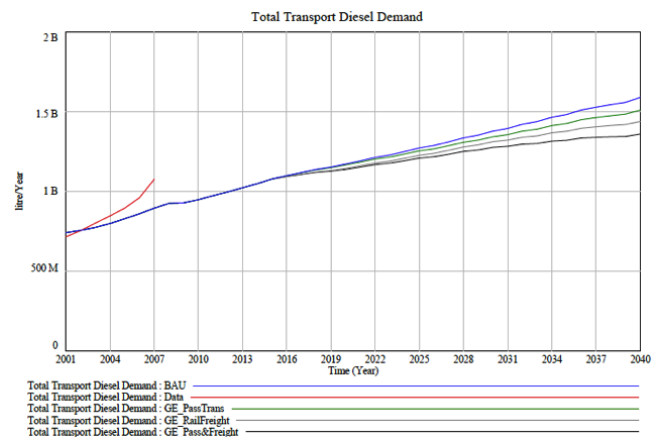


Fig. 7. Fuel demand reductions from the various transportation scenarios

(Source: York, Brent, and Musango [35])

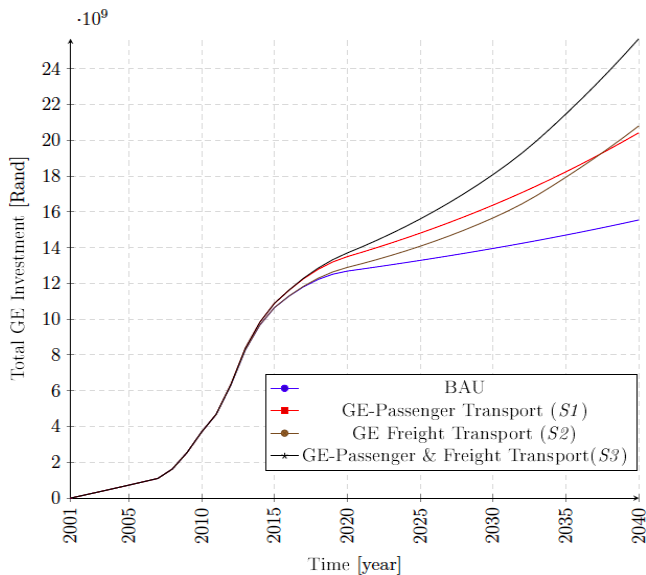


Fig. 8. Fuel demand reductions from the various transportation scenarios

(Source: York, Brent, and Musango [35])

B. Agriculture transitions

For the agriculture sector, a number of scenarios were derived, based on the increasing emphasis on organic and conservation farming (see Table 1).

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, Brent, and Musango [36])

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.

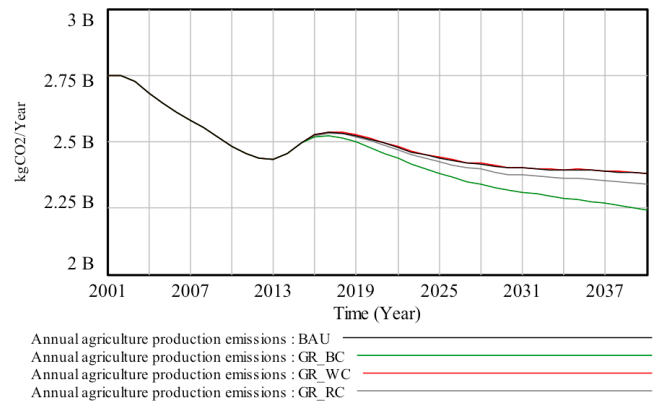


Fig. 9. Carbon reductions from the various agricultural scenarios

(Source: van Niekerk, Brent and Musango [36])

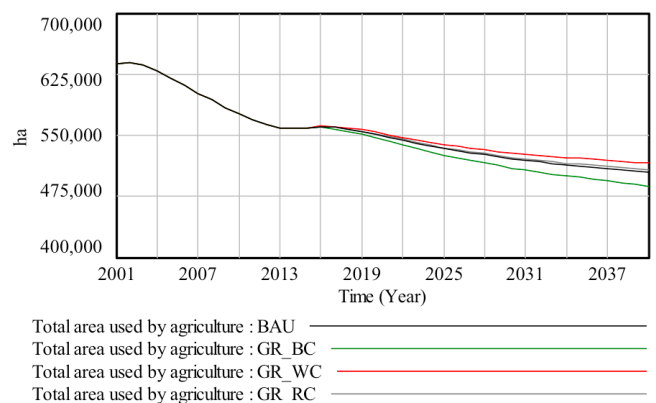


Fig. 10. Land requirements of the various agricultural scenarios

(Source: van Niekerk, Brent and Musango [36])

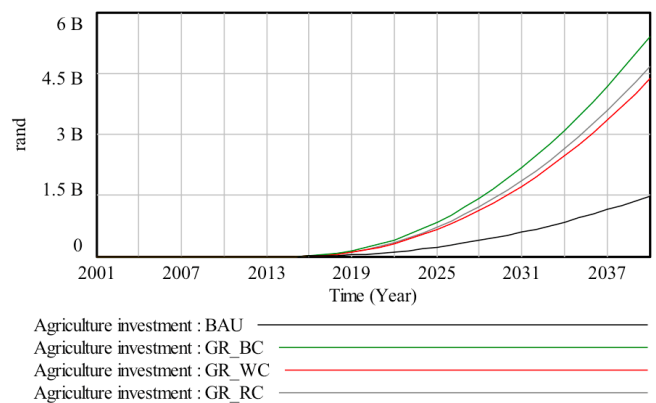


Fig. 11. Investment requirements of the various agricultural scenarios

(Source: van Niekerk, Brent and Musango [36])

C. Energy transitions

Two main categories of scenario were investigated for the electricity sector [37]. 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 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.

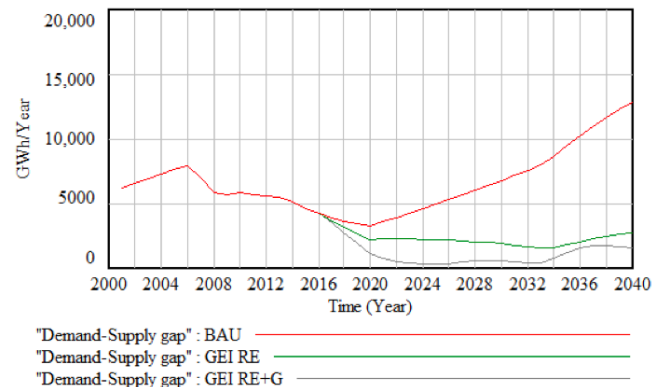


Fig. 12. Demand-supply gap analysis for the three scenarios

(Source: Oosthuizen and Brent [37])

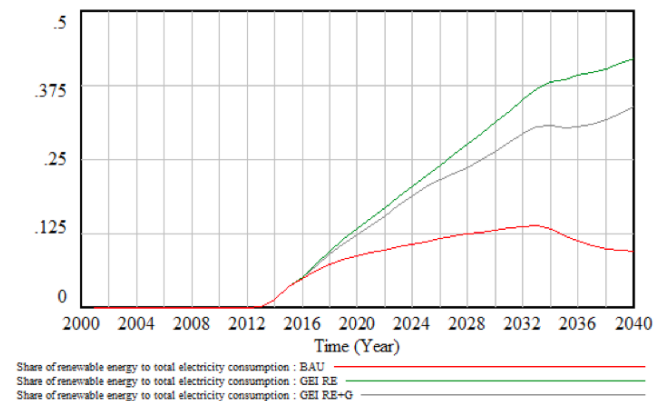


Fig. 13. Share of renewable energy for the three scenarios

(Source: Oosthuizen and Brent [37])

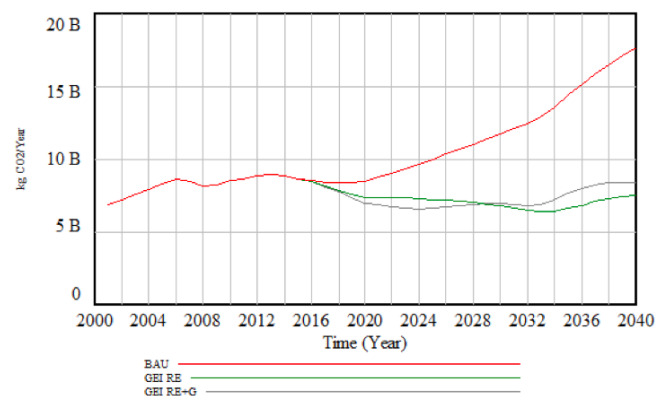


Fig. 14. Carbon emissions for the three scenarios

(Source: Oosthuizen and Brent [37])

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.

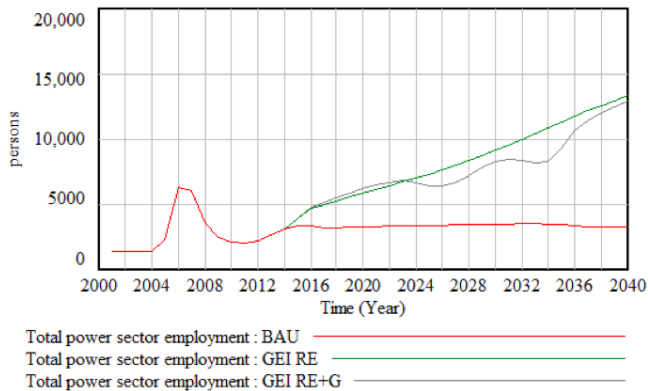


Fig. 15. Total employment created in the energy sector for the three scenarios

(Source: Oosthuizen and Brent [37])

V. 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 [38]. However, transitioning to sustainable socio-technical systems depends on both technological and far-reaching behavioural innovations [13] that are unique and cannot develop without fundamentally rethinking economic and wider societal conditions [39]. 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 [40] 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 [40].

From the perspective of sustainable development, Tran [13] 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 [41] 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 [42] and Brent [9] 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 [43] into technology management practices (see Figure 16), specifically to establish appropriate performance metrics for technologies with stakeholders in society, in a transdisciplinary way [9].

With regard to developing countries, especially, Lachman [44] 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, Berkhout, and van Beukering [45] 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 [46].

¹ De Kock [46] 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.

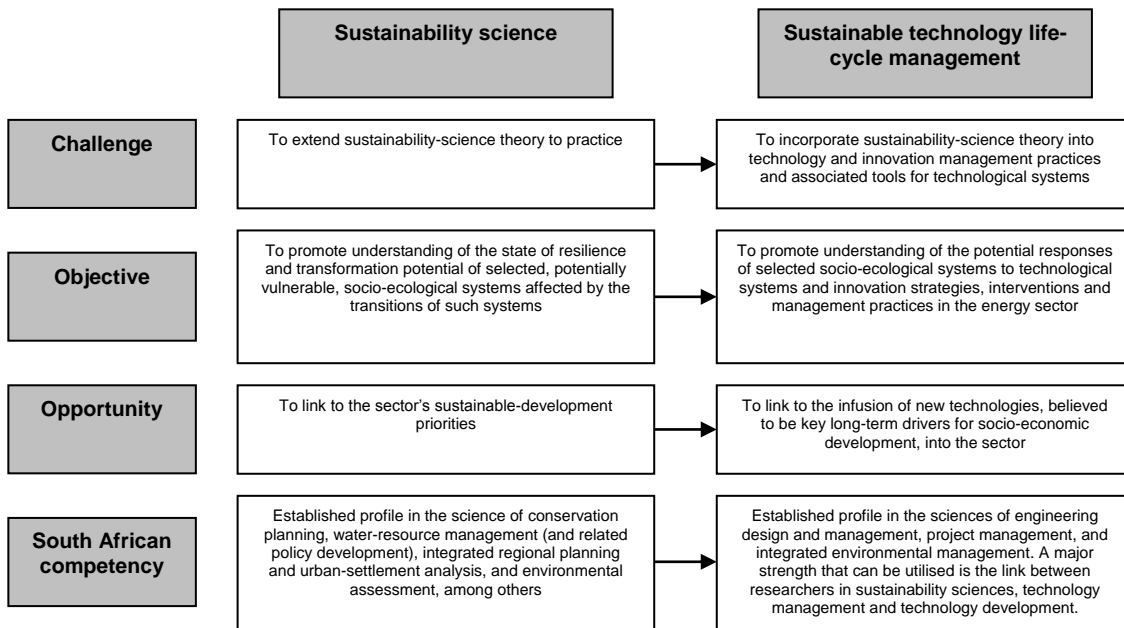


Fig. 16. Extension of the sustainability science field to technology management

(Source: Brent [9])

VI. 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.

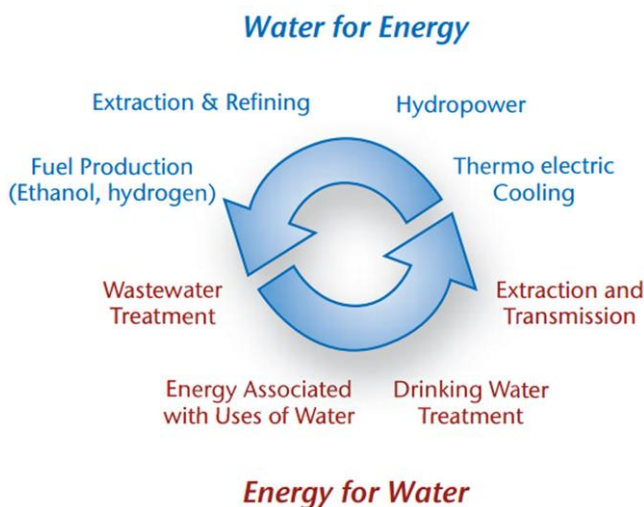


Fig. 17. The water-energy nexus

(Source: WBCSD [47])

Climate change has been termed a 'megaforce' [48] 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 [1], 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 [4]– 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 [5], 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 [48] 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 [46], that will play a vital role as we embark on a pathway to sustainable futures.

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