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Graduate School of Technology Management

Complex Technology Roadmap Development in the Context of Developing Countries

by

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Submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in the

Graduate School of Technology Management
Faculty of Engineering, Built Environment and Information
Technology

University of Pretoria, South Africa

February 2018



THESIS SUMMARY

Complex Technology Roadmap Development in the Context of Developing Countries

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Abstract

Technology roadmaps are useful for much longer technology planning periods in which past performance might not determine the future. They are also very useful in translating strategies into implementable actions, with clear targets and timelines. A growing number of organisations, industry associations, national governments and international agencies are also using technology roadmaps for future technology planning and analysis.

This research responds to the complexities associated with technology roadmap development in South Africa and other developing countries. It seeks to investigate whether the predominant literature on technology roadmaps and technology roadmapping is suitable for developing countries or if the existing frameworks need to be customised to suit framework conditions for developing countries. The following are the main research questions: 1) what are the unique



framework conditions for innovation in developing countries and 2) what is a suitable technology roadmapping framework for developing countries? The research sub-questions associated with the first research question are 1) what are the main priorities for innovation in South Africa and 2) what are the actual/perceived innovation competitive advantages for South Africa? The research sub-questions associated with the second research question are: 1) what is the nature and characteristics of technology roadmaps in South Africa and 2) what are the critical factors for successful technology roadmaps in South Africa?

Relevant literature reviewed in this research includes knowledge evolution of the technology roadmapping field, nature and impact of emerging technologies as well as technology management in developing countries. The mainstream technology roadmapping literature is useful in guiding technology roadmapping efforts in developing countries, although the intention of this study was also to determine its 'fitness for purpose'. A literature review led to the development of the theoretical framework for technology roadmapping in developing countries. The key elements of this framework are the multilevel perspective analysis based on complex systems theory, transition management theory and leapfrogging as technology catch-up strategy.

The methodology adopted for this research was informed by a theoretical framework developed and a literature review. The research design is based on post-positivism research philosophy (realism perspective). As a result, both a quantitative survey and qualitative interviews were used to collect data. Data collection tools used were online quantitative survey as well as semi-structured qualitative interviews. The information collected from qualitative interviews along with secondary data (documents analysis) were used to assist in interpreting patterns of responses received from quantitative survey data.

The five deduced analytical propositions regarding the innovation dynamics in South Africa, as a case for developing countries, address the key issues to consider in transitioning the complex innovation systems. Building from the



findings regarding the innovation dynamics within the developing countries, the additional five propositions provide some foundation and principles for technology roadmapping in developing countries. These incorporate usage of the third generation technology roadmaps in the developing countries, importance of timing the window of opportunity, the recommended usage of scenario planning, a balance between involvement of stakeholders from dominant product-technology platform and those who are transition-oriented and the importance of monitoring and updating the transition-based technology roadmaps.

The ten analytical propositions deduced were further tested and demonstrated through the analysis of sociotechnical transitions taking place within the energy, mining and water sectors in South Africa. The common innovation landscape factors that are incorporated for long-term technology planning in these sectors are the economic climate, government policy and public discourse. All three plans also begin with a transition phase that entails predevelopment of multiple emerging technologies that are characteristic of the third generation technology roadmaps.



LIST OF PAPERS PUBLISHED BY THE CANDIDATE

Published Papers

Letaba, P., Pretorius, M.W. and Pretorius, L. (2017) Sociotechnical transitions and technology roadmaps in South Africa. In *Proceedings of the R&D Management Conference*, Leuven, Belgium.

Letaba, P., Pretorius, M.W. and Pretorius, L. (2017) Technology roadmapping and fourth industrial revolution: a case of mining automation roadmapping. In *Proceedings of International Association for Management of Technology (IAMOT) Conference*, Vienna, Austria.

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ACKNOWLEDGEMENTS

I would like to pass my special appreciation to my supervisor, Prof. Tinus Pretorius, and the co-supervisor, Prof. Leon Pretorius, for all the guidance and support I received from them during my PhD studies. Their patience and wisdom have contributed significantly for completion of this research.

Let me acknowledge the Department of Science and Technology (DST) and the National Advisory Council on Innovation (NACI) for the financial support received for completion of PhD qualification.

Partial support received from Eskom Tertiary Education Support Programme (TESP) for research related to energy technology roadmaps is also acknowledged.

I am grateful for all respondents and organisations who provided data and information for the purpose of this research. In particular, the Council for Scientific and Industrial Research (CSIR) which allowed me to conduct pilot quantitative survey with their staff. Dr Neil Trollip was very helpful in providing relevant CSIR staff contacts.

The love and patience received from my family are acknowledged. More specifically, my wife Tshegofatso Phasha and my lovely children: Tshepo, Tshepang and Tshepiso.

This thesis is dedicated to my late younger sister, Makhothatso Letaba, who passed away at the peak of my PhD research. Your memory will live with us forever.



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LIST OF ACRONYMS AND ABBREVIATIONS

The following is a list of acronyms and abbreviations together with a first page they appear:

Acronym/ Abbreviation	Definition	Page
CCS	Carbon Capture and Storage	128
CHP	Combined Heat and Power	134
CMOS	Complementary Metal-Oxide Semiconductor	32
CO ₂	Carbon Dioxide	128
CoEs	Centres of Excellence	134
CSIR	Council for Scientific and Industrial Research	vi
CSP	Concentrated Solar Power	127
DOE	Department of Energy	113
DST	Department of Science and Technology	vi
DWS	Department of Water and Sanitation	112
FDI	Foreign Direct Investment	41
FTTx	Fiber to the x	202
GDP	Gross Domestic Product	5
GERD	Gross Expenditure on Research and Development	65
HFCT	Hydrogen Fuel Cell Technology	134
HFV	Hydrogen Fuelled Vehicle	134
HySA	Hydrogen South Africa	133
HTP	Horizontal Technology Policy	65
ICT	Information and Communication Technology	2
IEA	International Energy Agency	1
IoT	Internet of Things	34
IP	Intellectual Property	41
IPP	Independent Power Producer	129
IPR	Intellectual Property Rights	41
IRP	Integrated Resource Plan	99
ITRS	International Technology Roadmap for Semiconductors	1



LHD	Load, Haul and Dump	145
MNC	Multinational Corporation	39
MW	Megawatt	128
MWe	Megawatt Electric	132
NACI	National Advisory Council on Innovation	vi
NASA	National Aeronautics and Space Association	1
NDP	National Development Plan	129
NPD	New Product Development	101
NPO	Not-for-Profit Organisation	76
PBMR	Pebble Bed Modular Reactor	132
PGM	Platinum Group Metal	134
PV	Photovoltaic	127
R&D	Research and Development	2
RDD	Research, Development and Deployment	147
RDI	Research, Development and Innovation	112
RDS	Respondent-Driven Sampling	164
SACCCS	South African Centre for Carbon Capture and Storage	130
SANEDI	South African National Energy Development Institute	130
SA-STTRM	South African Solar Thermal Technology Road Map	128
SETRM	Solar Energy Technology Roadmap	1
SME	Small and Medium Enterprise	47
SMME	Small, Medium and Micro Enterprise	7
SNAP	Systems for Nuclear Auxiliary Power	21
S&T	Science and Technology	23
TESP	Tertiary Education Support Programme	vi
TM	Technology Management	9
TRM	Technology Roadmap	9
WADER	Water Technologies Demonstration Programme	148
WRC	Water Research Commission	112
WTG	Wind Turbine Generator	130



CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Strategic role of technology roadmaps

Technology roadmaps are commonly used around the world as technology to market planning tools, especially within the multiple stakeholder environments where the intended future needs to be clearly communicated to various role players such as the innovators, entrepreneurs, customers, suppliers and the government.

They are also very useful in translating strategies into implementable actions, with clear targets and timelines. Motorola is one of the first organisations that made use of technology roadmaps in the 1970s to facilitate production of strategic product plans that are documented, tracked and updated as the relationship between technologies and marketplace unfolds (Willyard & McClees, 1987). Technology roadmaps assisted Motorola to integrate corporate planning processes with technology planning efforts in order to deliver value to the market and to maintain the company's competitiveness.

A growing number of organisations, industry associations, national governments and international agencies are using technology roadmaps for future technology planning and analysis. Examples of such roadmaps are the International Technology Roadmap for Semiconductors (ITRS), several International Energy Agency (IEA)'s low-carbon technology roadmaps, the South African Solar Energy Technology Roadmap (SETRM) and NASA technology roadmaps. Technology roadmaps exist in different formats and have diverse purposes as shown by Phaal, Farrukh and Probert (2001).

Although this technique was initially utilised for integrated market, products, technology and research planning, various scholars have recently introduced frameworks for service technology roadmaps (Cho & Lee, 2014; Suh & Park, 2009; Wells et al., 2004). Geographically, technology roadmaps are currently



being used in different parts of the world, including developed and developing countries, many applied in the energy sector.

There exist various other technology future planning and assessment tools such as foresighting, forecasting, technology intelligence, etc. According to Porter et al. (2004:291), “time horizon strongly affects methodological appropriateness” and “extrapolative approaches are usually suitable only for shorter terms”. Technology roadmaps are useful for much longer technology planning periods in which past performance might not determine the future. Although both technology roadmaps and foresight seek to collect and document future technology expectations in terms of what is likely to happen, technology roadmaps combine this with future desires of the key stakeholders and commitments from these stakeholders (McDowall, 2012).

Overall, the role of technology roadmaps around the world remains that for selection of candidate technologies that are in line with business strategy, anticipation of the emerging technology trends and to aid in unlocking technological value for new sources of growth.

1.2 Context of research

South Africa also adopted the use of technology roadmaps, and the majority of these are driven by the national government through various sector departments. The public sector technology roadmaps in South Africa are often developed as an action plan for implementation of national strategies. For example, the ICT Research and Development (R&D) and Innovation Technology Roadmap was developed by the DST and CSIR as an implementation plan to guide the National ICT R&D and Innovation Strategy (Smith & Meyer, 2016).

Due to perceived lack of local expertise, most of these technology roadmaps are developed through the assistance of international experts who use established theories and frameworks in this field. However, there are serious challenges



being encountered during the development of these roadmaps and these include the inability to partner with the private sector for development and implementation of the roadmap as well as difficulty in prioritising products, technologies and research.

This research therefore responds to these complexities associated with technology roadmap development in South Africa. It seeks to investigate whether the predominant literature on technology roadmaps and technology roadmapping is suitable for developing countries or if the existing frameworks need to be customised to suit framework conditions for developing countries such as South Africa. This is important to justify the effort taken to develop these technology roadmaps and to maximise their impact within the developing countries.

The study by Carvalho, Fleury and Lopes (2013) concluded that the field of technology roadmapping is still a relatively new area and there are more issues to be addressed by future research such as:

- A move from exploratory based studies to more quantitative research.
- The empirical evidence on the significant impact of technology roadmaps on innovation or organisational performance.
- Establishment of benchmarks for critical success factors for application of technology roadmaps.
- Linkage between technology roadmapping and other innovation and corporate strategy linked initiatives such as strategic resources and competencies, knowledge management, organisational communications, the management of stakeholder relations and sustainability drivers.

It should be noted that the term 'technology roadmapping' refers to a process for development of technology roadmaps while the term 'technology roadmap' is an output of such a process. This research is concerned with both issues.



1.3 Research objectives and main research questions

In alignment to the stated context of research, the objectives of this research are therefore:

- i) To investigate innovation planning in developing countries in terms of priorities, opportunities and challenges; and
- ii) To develop an appropriate framework for technology roadmapping in developing countries with South Africa as a case country.

Since technology roadmaps function as a strategic lens that provides a high-level view of the innovation system in question (Phaal & Muller, 2009), it is important to understand the innovation and technology management framework conditions in developing countries prior to the development of the technology roadmapping framework. There are a plethora of studies on management of technology and innovation in developing countries (van der Boor, Oliveira & Veloso, 2014; Zanello et al., 2015; Razek, Hassan & Alsanad, 2015) although the focus is often divorced from the technology roadmapping framework.

The following are the main research questions addressed in this thesis:

1. What are the unique framework conditions for innovation in developing countries?
2. Can technology roadmapping practices be adapted for developing countries' framework conditions?

1.4 Research sub-questions

The following are the research sub-questions associated with each main research question:

Main Research Question 1: unique framework conditions for innovation in developing countries

1. *What are the main priorities for innovation in South Africa?*



The national system of innovation practitioners have raised concerns regarding lack of research, technology and innovation prioritisation in South Africa (ASSAf, 2013). Prioritisation was more effective during the 'apartheid' government era as witnessed by large industries that were successfully established. The 1996 White Paper for Science and Technology sought to promote the idea of inclusive innovation and there have been several research and innovation strategies that seek to steer the country's innovation system. At the firm level, most companies prioritise efficiency over innovation as South Africa is one of the efficiency driven economies (Langevang et al., 2015). However, there are several pockets of excellence for both research and innovation, an example being a flagship Square Kilometre Array project.

2. What are the actual/ perceived innovation competitive advantages for South Africa?

Although the country has an abundance of mineral deposits such as gold and platinum, mining sector value-added as percentage of gross domestic product (GDP) has been on the decline (Kaplan, 2015). This is also the case for the manufacturing sector, although the chemical sector is very competitive. With the diversity of innovation competencies in South Africa, there is no consensus on a set of key competitive advantages for the country. This gap also exists in the literature.

Main Research Question 2: technology roadmapping framework for developing countries

3. What are the nature and characteristics of technology roadmaps in South Africa?

There are various types of technology roadmaps that have been developed in South Africa. Although the majority of these are in the public sector, there are several companies that make use of them. Since technology roadmaps contain strategic information about how the company sees the future unfolding, private



companies often keep them confidential. Not much has been written in the literature about the technology roadmapping process in South Africa, although there are few papers that discuss specific case roadmaps (Brent & Pretorius, 2012). This builds a strong case for the need to understand the fundamentals and key principles for technology roadmapping in developing countries.

4. What are the critical factors for successful technology roadmaps in South Africa?

Although technology roadmaps have been adopted by technology and innovation management practitioners and policymakers around the world, the evidence of their impact is still a contested topic. McDowall (2012:534) suggests that it is impractical to evaluate the outcome of technology roadmaps “given the severe difficulties of attribution in a context as complex as an innovation system”. Instead, the author suggests a four indicator criteria to evaluate technology roadmapping processes, namely: i) credibility in terms of plausibility of the future pathway, ii) desirability of the intended future pathway by key stakeholders, iii) utility in terms of providing a coherent direction and iv) adaptability in terms of frequent updates and review of the technology roadmap.

1.5 Contributions of this study

This study has embraced the need to combine technology roadmapping frameworks with other technology management tools such as complex system and transition management theories in order to address unique technology planning challenges being experienced by developing countries. The following are the main contributions of this study:

- *Understanding and Critically Evaluating the Evolution of Technology Roadmapping Literature.*

A systematic overview of the literature of the evolution of technology roadmapping research field (Letaba, Pretorius & Pretorius, 2015) has shown



that there are three co-existing generations of technology roadmapping processes, as discussed in chapter 2, section 2.2.1. The findings from this work are useful in understanding and assessing the state of technology roadmapping paradigm thinking. It is important to understand how different technology roadmapping frameworks can be distinguished from each other and how they can be applied in different circumstances in a country, industry or an institution.

- *First Overview of the Relationship between the Fourth Industrial Revolution and Technology Roadmapping Framework.*

Third generation technology roadmaps involve convergence of multiple emerging technologies (Giasolli et al., 2014) that can complement or compete with each other. As the fourth industrial revolution/ digital evolution involves convergence of various emerging technologies, an exploratory investigation of the relationship between an industry 4.0 and the technology roadmapping frameworks was done through this study (Letaba, Pretorius & Pretorius, 2017).

- *Appreciation of Emerging Technologies as Vital Factor for Niche Experimentation in Developing Countries.*

There is a strong appeal for policymakers in developing countries to prioritise certain technologies with proven competitive advantage. This study encourages predevelopment of niche innovations through emerging technologies, which is followed by technology selection, upscaling and retention. Possible industrial impact of emerging technologies was demonstrated through this study (Letaba, Pretorius & Pretorius, 2014). According to Hochberg (2016), there is an increase of the use of the seed accelerator model in assisting the small, medium and micro enterprises (SMMEs).

- *Proposal of Technology Roadmapping Framework and Principles for Developing Countries.*



The proposed technology roadmapping framework is likely to be an important managerial toolbox for development of technology roadmaps in complex innovation systems through application of multilevel perspective and transition management theory. This framework applies a systems thinking perspective to technology roadmapping frameworks and it incorporates this with the transition management theory for sociotechnical systems.

1.6 Thesis structure and research roadmap

As depicted in Figure 1.1, the preliminary step in answering the stated research questions is an in-depth systematic literature review (Chapter 2) on the evolution of the technology roadmapping field, the strategic importance of emerging technologies as well as technology management in developing countries. This in-depth literature review sets a foundation for answering of the two main research questions articulated in this chapter, about the suitable technology roadmapping frameworks for developing countries and the innovation dynamics in developing countries.

The conceptual framework for technology roadmapping in developing countries (Chapter 3) is informed by the literature review and further theoretical frameworks on multilevel analysis of a complex innovation system and transition management.

The research methodology (Chapter 4) outlines the research design as well as data collection techniques used such as quantitative survey, qualitative interviews and a desktop study. The questionnaire design was primarily informed by the literature review as well as the conceptual framework.

Chapters 5, 6 and 7 contain the results and in-depth discussions to synthesise the information collected in relation to the research questions. The innovation dynamics in South Africa (Chapter 5) give context to the nature and characteristics of technology roadmaps (Chapter 6).

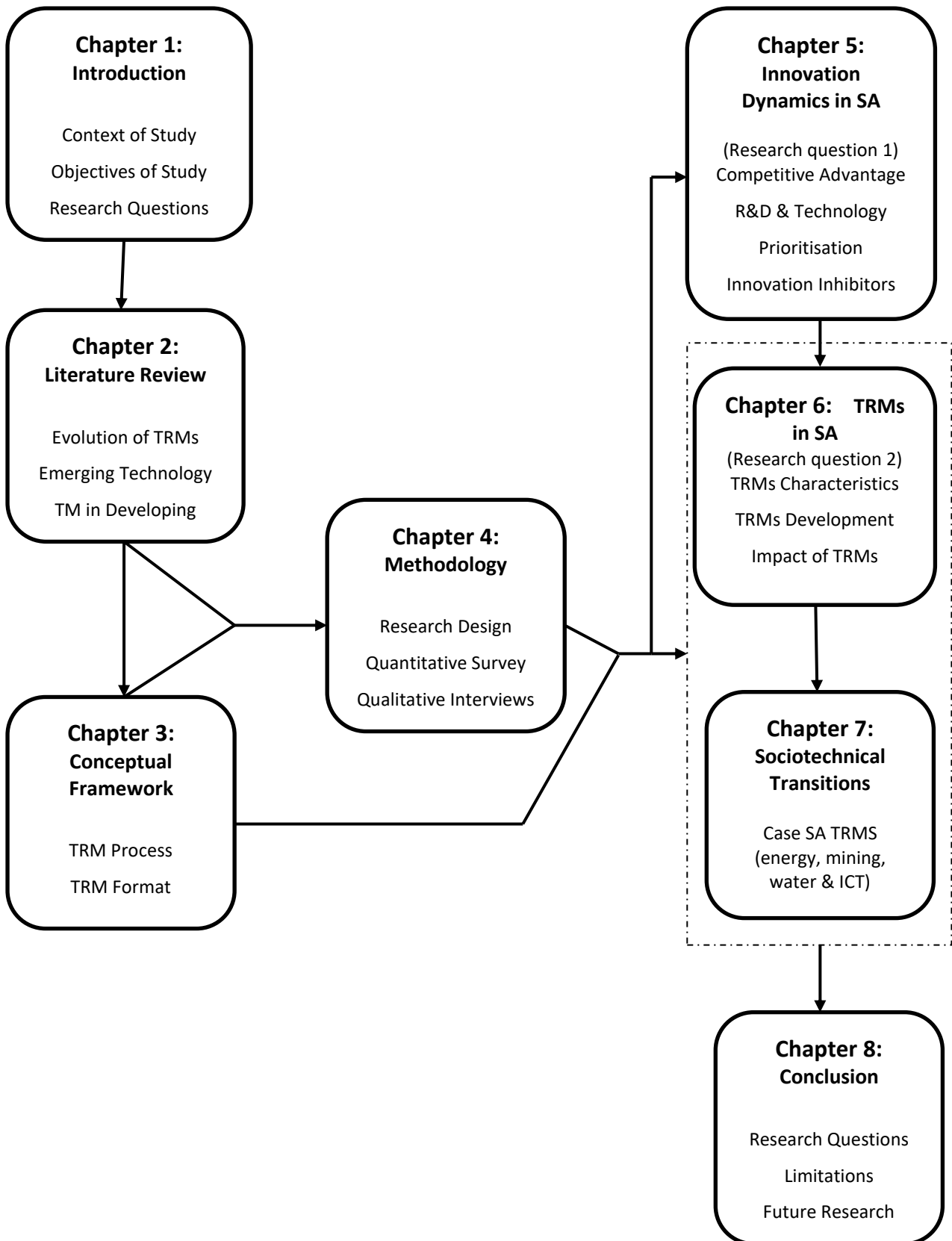


Figure 1.1: thesis structure and flow of chapters



The conceptual framework derived in Chapter 3 is used as an analytical framework for South African technology roadmaps. Some case technology roadmaps in various sectors are used to investigate the nature of sociotechnical transitions taking place (Chapter 7).

Finally, in the conclusion section (Chapter 8) the reflection is made on the novel contributions and whether the research questions were answered, the limitations of this study are indicated and further future research is suggested.

1.7 References

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CHAPTER 2: LITERATURE REVIEW ON TECHNOLOGY ROADMAPS AND TECHNOLOGY MANAGEMENT AND A LINK TO DEVELOPING COUNTRIES

2.1 Introduction

A synthesis of literature on knowledge evolution of the technology roadmapping field, emerging technologies and technology management in developing countries is intended to develop a theoretical framework for technology roadmapping in developing countries and also to inform the research methodology. Mainstream technology roadmapping literature is useful to guide technology roadmapping efforts in developing countries, although it is the intention of this study to determine its 'fitness for purpose'.

The knowledge evolution of the technology roadmapping field shows the emergence of third generation technology roadmaps which involves convergence of multiple emerging technologies. Hence the literature on emerging technologies would be useful for in-depth understanding of this convergence. As technology roadmaps are a strategic lens to the innovation dynamics taking place (Phaal & Muller, 2009), the theoretical aspects of technology management in developing countries are critical to understand in order to develop technology roadmaps for developing countries.

2.2 Knowledge evolution of technology roadmapping field: the emergence of third generation technology roadmaps

Although technology roadmaps were popularised by Motorola for their usefulness in integrating corporate strategy and technology planning, their earlier usage was for planning of technological capability for the space programme (Anderson, 1982; Breslow, 1980). An earlier definition of a technology roadmap provided by Anderson (1982) was that of "a path consistent with mission needs and schedules". Technology roadmapping has evolved into a research discipline on its own and as a result, there are now more



sophisticated methodologies for the development, implementation and maintenance of technology roadmaps.

2.2.1 Three generations of technology roadmaps

Technology roadmapping as a research field is evolving, from a simple process that focused on the incorporation of technology in corporate planning processes (Phaal, Farrukh & Probert, 2004), to a more robust knowledge generating process in managing the complex innovation systems. The words 'technology roadmap' and 'technology roadmapping' are often used interchangeably (Igartua, Garrigós & Hervas-Oliver, 2010; Winebrake, 2004), and this is also the case for this study to some extent; although it should be noted that technology roadmapping is a process and technology roadmap is a product of such a process.

There are typically three generations of technology roadmapping approaches. The first generation technology roadmapping is a product-technology roadmapping which is concerned with a continuous product-technology platform. These types of technology roadmaps are typically based on a single root technology (Tierney, Hermina & Walsh, 2013) such as a transistor for the semiconductor industry. The type of technologies associated with the first generation technology roadmapping are typically sustaining, of which according to Kostoff, Boylan & Simons (2004), are known to improve the performance of existing products through the current product-technology paradigm.

A stable product-technology platform typically has platform leader(s) within a global value-chain that coordinates an ecosystem of suppliers that have the complementary products in order to provide a complete solution to a customer (Cusumano & Gawer, 2002). Therefore first generation technology roadmaps are aimed at facilitating communication between the platform producers and complementary products suppliers in order to contextualise future technological system requirements in relation to the changing customer needs.



In the case of second generation technology roadmaps, the focus is on “forecasting the development and commercialisation of a new or emerging technology” (Walsh, 2004), hence it is called an emerging technology roadmap. Such forecasting is achieved mainly through an analysis of life cycle differences between an emerging technology of interest and a current root technology in order to predict a potential technology transition point (Tierney, Hermina & Walsh, 2013). The emerging technologies can be sustaining or disruptive, depending on their complementarity with an existing product-technology platform (Husig & Hipp, 2009; Tan & Henten, 2006), although according to Overdorf & Barragree (2001), new technologies typically have some sustaining or disruptive features.

The strategic role of emerging technology roadmaps depends on whether the roadmapping effort is pursued by an incumbent with a stable product-technology platform or a challenger who needs to explore the potential product platforms. Incumbents are often threatened by rapid and radical technological discontinuities (Rothaermel, 2001), and as a result, technology roadmapping assists with the identification of future threats and for organisational learning in adapting to an uncertain future. Technology roadmapping in a context of a challenger, without an established product-technology platform, serves a purpose of facilitating a rapid commercialisation pathway through an establishment of a new value network and in convincing the customers to adapt/change their preferences (Rothaermel, 2001).

Motorola’s technology roadmapping efforts involved mainly the first generation technology roadmapping although they also made use of a second generation roadmapping approach (Willyard & McClees, 1987). An emerging technology roadmap was used by the company to (i) do an objective evaluation of technology capabilities, (ii) to determine the current and future comparison of Motorola’s capabilities to that of its competitors, and (iii) to forecast the future technological progress (Willyard & McClees, 1987). According to the authors, Motorola used the product-technology roadmaps to track a company’s progress



in product and process development in a context of the marketplace, competition and historical performance.

A third generation technology roadmapping approach proposed by several authors (Tierney, Hermina & Walsh, 2013; Gindy, Arman & Cavin, 2009; Kamtsiou et al., 2014) recognises the changing nature of technological innovation in a sense that most of the current innovations depend on converging or competing multiple root technologies (Kamtsiou et al., 2014). Complex interactions and technology developments are done without an obvious direct benefit of the predetermined architecturally stable product-process platforms (Tierney, Hermina & Walsh, 2013).

Since some main functions of technology roadmaps are to communicate the critical system requirements (Amer & Daim, 2010) and to communicate the relationships among markets, products and technologies over time (Lee & Park, 2005; Phaal, Farrukh & Probert, 2005), the third generation technology roadmaps communication becomes even more critical. Communication for the third generation technology roadmapping is aimed at a broader knowledge network of a company that incorporates potential complementary products and technologies. The key characteristic for third generation technology roadmapping is an absence of a clear product-process platform coordinator and the presence of other drivers such as regulation and culture in addition to market drivers (Tierney, Hermina & Walsh, 2013).

The three generations on technology roadmapping represent different research paradigms depending on the nature of innovation planning which is being addressed. Matured and large companies with a supporting value network of complementary partners might still prefer the use of the product-technology roadmapping or emerging technology roadmapping approaches whereas some high technology small companies and most developing countries' companies, without the established global competencies, might find the third generation



technology roadmapping approach being useful in planning a rapid commercialisation pathway.

These opposing paradigms result with some conflicting or different definitions. For example, a technology roadmap definition provided by Garcia & Bray (1997) as “a needs-driven technology planning process to help identify, select, and develop technology alternatives to satisfy a set of product needs” applies mainly to first generation technology roadmapping practice. There is also emergence of the other definitions for a technology roadmap. An outcome of these multiple definitions is an absence of a standardised definition for technology roadmapping or technology roadmaps (Phaal, Farrukh & Probert, 2004; Kamtsiou et al., 2004).

Another method of illustrating the evolution of technology roadmapping literature is its categorisation of focus according to best practice perspective (1987 – 2000), engineering perspective (2001 – 2010) and the organisational behaviour perspective from 2011 onwards (Simonse, Hultink & Buijs, 2015). The best practice theoretical perspective according to Simonse, Hultink & Buijs (2015) is dominated by case studies of roadmapping practice within the companies such as Motorola, Lucent, Philips, etc., whereas the engineering perspective seeks to generate knowledge that assists with the ‘how’ of roadmapping efficiently. Among some known processes invented are the ‘fast-start’ technology roadmapping workshop techniques introduced by Phaal, Farrukh & Probert (2004). The organisational behaviour perspective balances technology scouting input with opportunity scouting input and this is achieved through exchanging and co-creation of innovation roadmaps with the suppliers and other partners (Simonse, Hultink & Buijs, 2015).

The two recent articles by Carvalho, Fleury & Lopes (2013) and Gerdri, Kongthon & Vatananan (2013) systematically reviewed the technology roadmapping knowledge structure evolution. The first paper used a hybrid methodological approach that combines bibliometrics, semantic analysis and



content analysis to show technology roadmapping evolution from 1997 to 2011. This study identified several definitions of technology roadmapping/ roadmaps; various phases in the technology roadmapping process; analytical tools used by the technology roadmapping literature's authors; conditions necessary for development of a high quality technology roadmap; as well as limitations and advantages of the roadmap. Most authors agree with the alignment of technology with overall business objectives as a major benefit for technology roadmapping although there is no consensus on the limitations. A dominant research methodology used by most authors in technology roadmapping field is a case study followed by a literature review (Carvalho, Fleury & Lopes, 2013).

A paper by Gerdri, Kongthon & Vatananan (2013) used bibliometric analysis on the technology roadmapping's selected journal and conference papers for the period 1987 to 2010 to show an evolution of technology roadmapping literature by year, and furthermore showed which journals, conferences, countries and organisations are leading on technology roadmapping related research. The United States was shown to be the leading country followed by the United Kingdom; whereas University of Cambridge followed by Portland State University were shown to be the leading organisations. The University of Cambridge group is mainly focused on the engineering perspective of technology roadmapping (Simonse, Hultink & Buijs, 2015) and their research is based on issues such as fast-start technology roadmapping approach, technology strategy, product planning, business planning, competitive intelligence, citation analysis, patent analysis and text-mining (Gerdri, Kongthon & Vatananan, 2013).

2.2.2 Different types of technology roadmap formats

The generic technology roadmap format shown in Figure 2.1 is a simplified outcome of an extensive consultative process of matching future market needs to product portfolio, product portfolio to technological capability and desired technological capacity to portfolio of R&D projects. On the horizontal axis is the

time scale, and according to Kappel (2001), it is this explicit timing for technology roadmap targets that distinguish technology roadmaps from other strategy documents in the corporation.

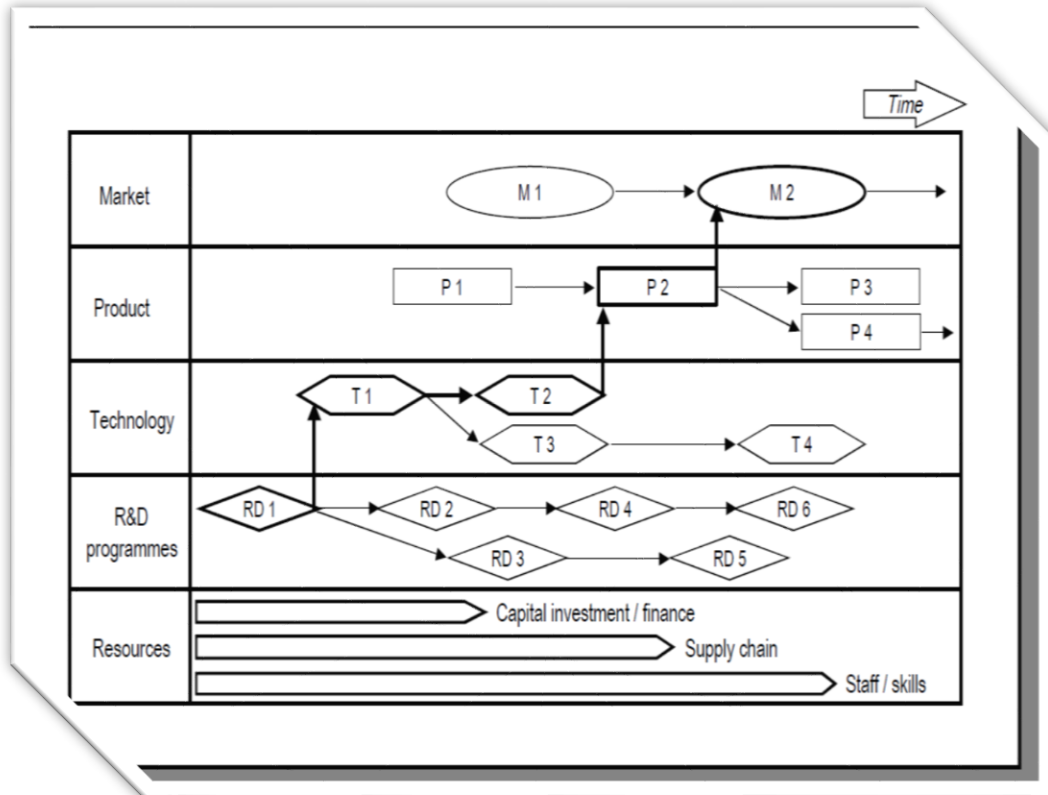


Figure 2.1: generic technology roadmapping model

Source: EIRMA (1997)

The vertical axis summarises current and future target market, product portfolio, technological capabilities and R&D project portfolio. The connecting arrows show how the future market (M2) preference can be fulfilled through product portfolio (P2), which in turn would need some requisite technological capability (T2). Under this generic technology roadmapping format, future technological capacity (T2) could be developed from current root technology (T1) which needs to be further developed through R&D programmes, RD1 in this case. Once this path is determined for fulfilment of the future market/ mission requirements, a complementary step is the resources commitment from various stakeholders.

These resources can include issues such as capital investment, supply chain and skilled staff.

Technology roadmaps are used by various institutions such as companies, science councils, industrial bodies, governments, international organisations, etc. This implies a different focus by various institutions undertaking this exercise, the notable differences being timescales and focus of technology roadmaps. Phaal, Farrukh & Probert (2001) summarise eight different types of technology roadmaps and different formats used to communicate them.

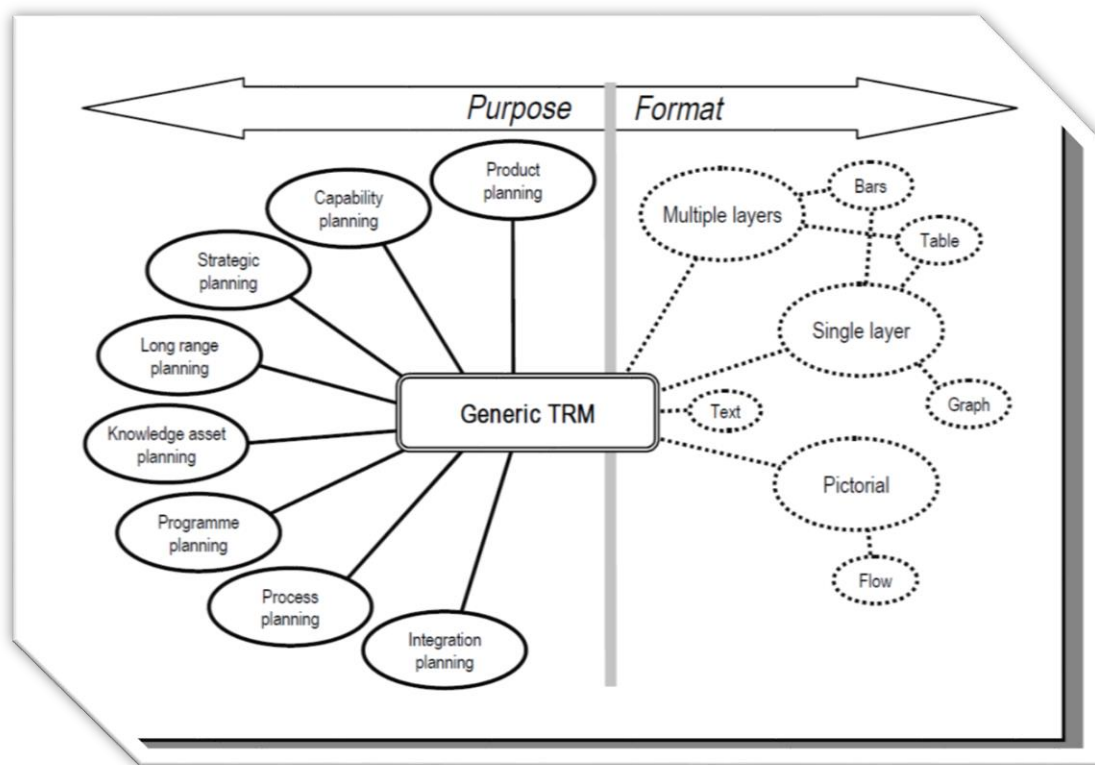


Figure 2.2: characterisation of technology roadmaps, purpose and format

Source: Phaal et al. (2001)

As shown in Figure 2.2, they are categorised in terms of product planning (development of technological capability for new generation products), service/capability planning (technology support to organisational capabilities), strategic planning (strategic path to achieve intended vision), long-range planning (extended foresight at sector or national level), knowledge asset planning



(alignment of knowledge management initiatives with business objectives), programme planning (project planning such as R&D programme), process planning (knowledge flow between different stakeholders in support of a particular organisational process) and integration planning (evolution of technology over time towards planned integrated outputs).

Although technology roadmaps are easily communicated through multiple layers on the vertical axis, according to Phaal, Farrukh & Probert (2001), there exists other formats of technology roadmaps such as single layer, text, graphs, tables, bars, pictorial and flow diagrams. Most technology roadmaps are a combination of several of these formats.

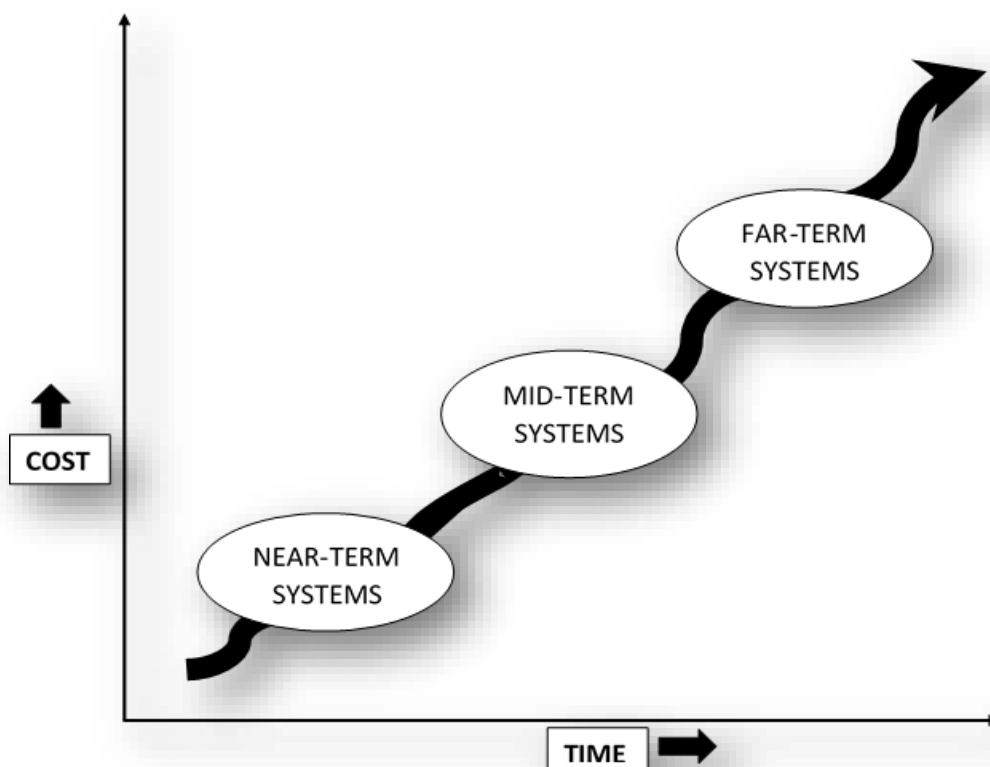


Figure 2.3: nuclear reactor power systems technology roadmap

Source: Anderson (1982)

An example of a graph format technology roadmap is shown in Figure 2.3. This is a technology capability planning technology roadmap for space mission nuclear reactor power system. In this Systems for Nuclear Auxiliary Power



(SNAP) programme technology roadmap, the users' space mission needs are correlated with the far-term, mid-term and near-term nuclear reactor power system technological capability (Anderson, 1982).

Technology roadmaps were further categorised by Karlsson & Dawidson (2003) in terms of roadmap emphasis and roadmapping purpose. As shown in Figure 2.4, on the bottom quadrants the purpose of technology roadmapping can be constrained to organisation level coordination (local) or at the industry level.

The emphasis of the technology roadmap on the bottom quadrants is shown to be positioning or mapping of trends/ trajectories. Combinations of roadmap emphasis and roadmapping purpose result with four types of technology roadmaps, namely: (i) science-technology roadmaps for setting industry targets, (ii) industry roadmaps for setting industry expectations, (iii) product-technology roadmaps to align business decisions and (iv) product roadmaps to schedule product introductions.

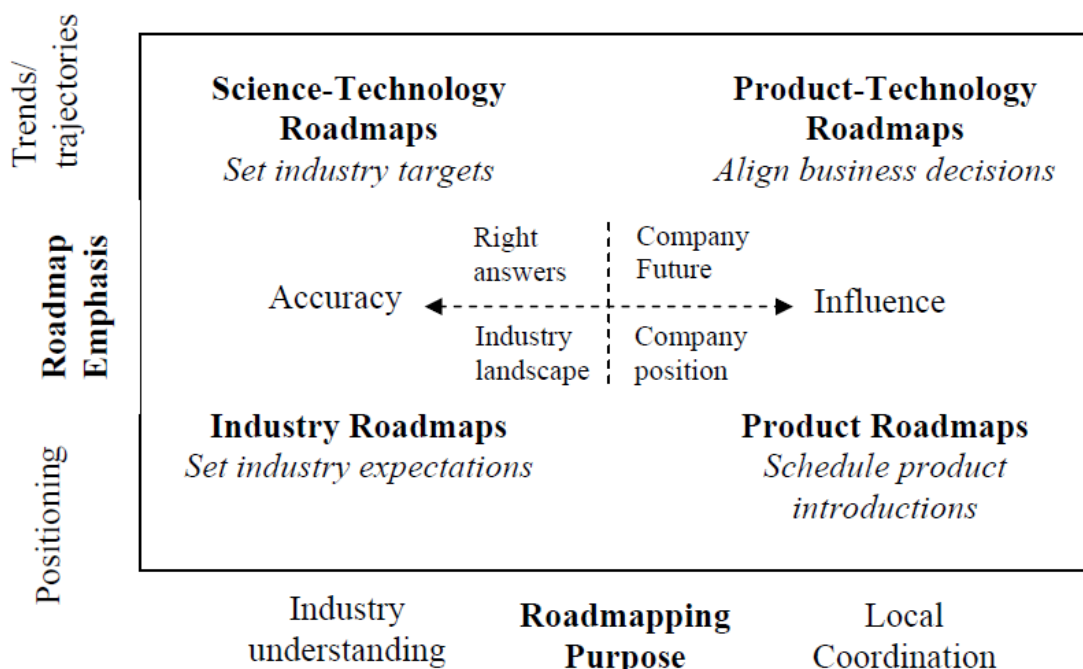


Figure 2.4: four types of technology roadmaps

Source: Karlsson & Dawidson (2003)



2.2.3 Technology roadmapping process

A proper technology roadmapping effort involves an extensive and a very costly exercise (Lee et al., 2008) to gather various future perspectives from the internal and external stakeholders. These stakeholder perspectives are categorised by Phaal & Muller (2009) in Figure 2.5 in terms of (i) commercial and strategic perspectives, (ii) design, development and production perspectives and (iii) technology and research perspectives. The stakeholders with commercial and strategic perspectives are mainly interested on market and business drivers, strategy and needs. These perspectives define a long-term vision and the reasons behind a technology path to be followed.

The design, development and production perspectives help to define products and services that can fulfil the vision set by commercial and strategic needs. Typical knowledge generated by these stakeholders during a technology roadmapping process is a potential product portfolio in terms of form, function and performance. Finally, the stakeholders with technology and research perspectives brainstorm about science and technology (S&T) capabilities that are needed to enable the desired product portfolio. The focus in this instance is about technological and scientific solutions and capabilities. Irrespective of what perspective is pursued by these various stakeholders, all of them need to address the questions of 'where do we want to go?', 'how can we get there?' and 'where are we now?'.

The facilitators have an important role to play during the technology roadmapping process. According to Tong & Li (2011), the technology roadmapping facilitator must understand the technology roadmapping methodology, although he/she should not necessarily be an expert or knowledgeable on the content of the area being roadmapped. This is important as technology roadmap owners need to be fully involved in its development (Garcia & Bray, 1997) to ensure that its development is not a once-off process that results in a document that gets shelved once it has been approved.

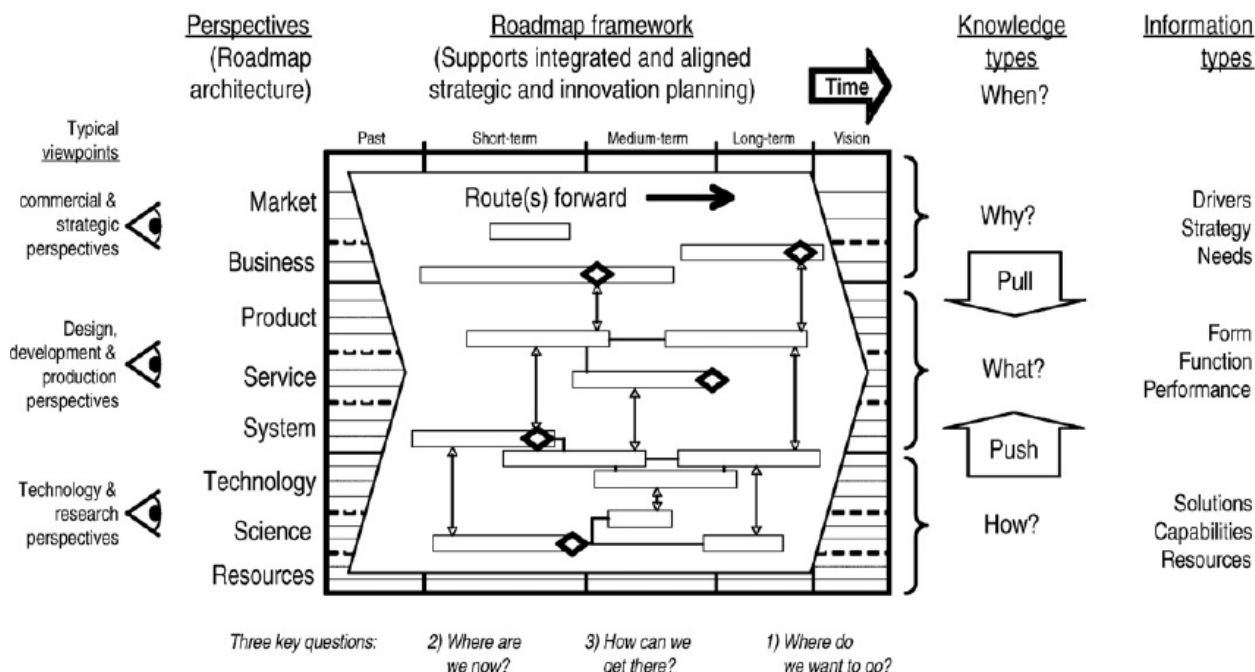


Figure 2.5: strategy alignment multi-layered technology roadmap

Source: Phaal & Muller (2009)

The facilitator’s role, according to Albright & Kappel (2003) is to define roadmapping scope and to form a cross-functional team that will support and guide the roadmapping team and to set-up the work plan. These authors emphasise the importance of the facilitator to challenge the assumptions and to force rigor into the roadmap.

There exist various guidelines on a process for development and implementation of technology roadmaps. Some known examples are IEA’s guideline for energy technology roadmaps and fast-start technology roadmapping approaches proposed by Phaal, Farrukh & Probert (2000).

The IEA technology roadmapping process shown in Figure 2.6 has four phases and it takes approximately between 6 to 18 months to develop a roadmap. All phases utilise a combination of expert judgement and consensus as well as data and analysis. Phase one involves planning and preparatory activities. For the expert and consensus work stream, this involves the establishment of technology roadmapping steering committee, determination of scope and

boundaries for the roadmap and identification of stakeholders and experts. This conceptualisation phase takes between one to two months.

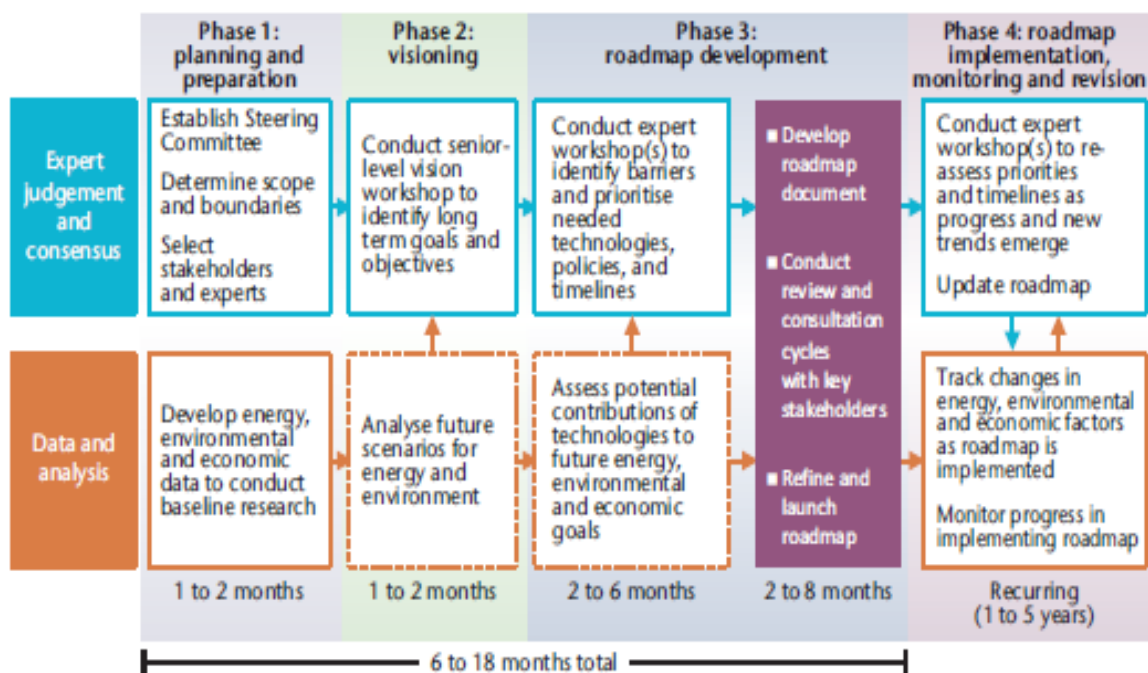


Figure 2.6: IEA technology roadmapping process

Source: IEA (2014)

The purpose of phase two of the IEA technology roadmapping process is to develop a vision; and this includes conducting of senior level workshops to identify long-term goals and objectives. In this one to two month phase, data analysis activities are analysis of industry future scenarios. Phase three involves the actual technology roadmap development activities and this can take between two to six months.

Major activities in this phase include conducting of expert workshops to identify barriers and to prioritise technologies, policies and timelines needed to fulfil the higher level objectives identified. Data analysis activities to support the technology roadmap development phase include assessment of the potential contribution of various technologies to support realisation of sector objectives and goals. As the technology roadmap is supposed to be a living document



(Amer & Daim, 2010), the last phase of the IEA technology roadmapping process involves roadmap implementation, monitoring and revision.

This IEA technology roadmapping process is well aligned to the technology roadmap framework suggested by Garcia & Bray (1997), which has three phases, namely: (i) preliminary activities phase, (ii) technology roadmap development phase and (iii) follow-up activities phase. The first two phases of the IEA process can be regarded as preliminary activities.

One of the fast-start technology roadmapping approaches proposed by Phaal, Farrukh & Probert (2000) is a T-Plan process which involves four half-day workshops (Figure 2.7). The first workshop entails the preliminary activities such as scoping of performance dimensions, understanding market/ business drivers, prioritisation as well as competitiveness and gap analysis.

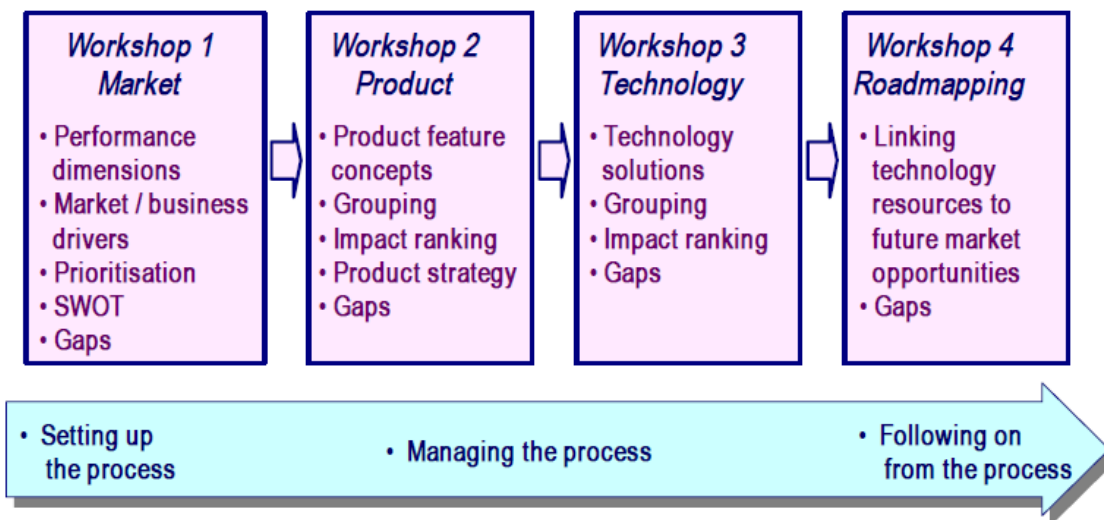


Figure 2.7: T-Plan fast-start technology roadmapping process

Source: Phaal, Farrukh & Probert (2000)

The second, third and fourth workshops involve the actual development of the technology roadmap in which the second workshop determines product features, grouping of products, impact ranking, product introduction strategy and gap analysis. The third workshop involves identification of technologies that will form part of the roadmap and these technologies are grouped, their impact



assessed and this is then followed by a gap analysis. Through the fourth workshop technology resources are linked to future market opportunities and gap analysis is also conducted.

Although a T-Plan technology roadmapping process is meant to be a fast roadmapping approach, its activities resemble other roadmapping processes such as the one proposed by the IEA. The follow-up activities is one missing key step in the T-Plan process, although the logic behind it might be the fact that this approach is mainly meant for rapid initiation of a technology roadmapping process.

An improved fast-start technology roadmapping approach is an S-Plan, a workshop-based approach for strategic appraisal, opportunity identification and exploration of new strategic innovation opportunities (Phaal, Farrukh & Probert, 2007). The S-Plan technology roadmapping approach facilitates strategic planning and it is designed mainly for strategy and innovation processes. This approach adopts a standard three phase approach as it entails planning, a workshop and review. The workshop includes activities such as identification of strategic landscape, identification of innovation opportunities, exploration of priority opportunities and a way forward.

Once the technology roadmap is developed, a critical challenge is to implement its targets and to keep it alive as the innovation landscape changes (Vatananan & Gerdri, 2013). The Technology Development Envelope (TDE) framework which was introduced by Gerdri (2007), and uses the combined Delphi method and Analytical Hierarchy Process (AHP), is useful for technology forecasting, assessment and selection in relation to the organisation's objectives. This technique is also useful for reprioritisation of technologies as the organisation's environment or technology landscape changes. This addresses many weaknesses in keeping the roadmap alive.

A generic TDE framework entails 1) technology forecasting, 2) technology characterisation, 3) technology assessment, 4) hierarchical modelling (objective,



criteria, factors and measures of effectiveness), 5) technology evaluation and 6) formation of technology development envelope. Chan (2013) successfully demonstrated the use of TDE roadmapping framework in developing a strategic policy choice framework for technological innovation within the Chinese pharmaceutical industry. Similarly, this technology evaluation framework has been used by Gerdri & Kocaoglu (2007) to build a decision model to assess the contributions of emerging technologies and to evaluate their impacts on a country's objective.

2.2.4 Summary of technology roadmapping literature

The discussion about evolution of technology roadmapping generations shows the increased need to plan for emerging single and multiple root technologies, in search of the new sources of growth and competitiveness. The best practice, engineering and organisational technology roadmapping perspectives articulate a response from technology roadmapping practitioners and scholars in navigating through this evolution. The best practice perspectives treated all technology roadmaps as similar, mainly influenced by large companies such as Motorola, Lucent and Philips (Simonse, Hultink & Bijs, 2015). The engineering perspective allowed for differentiation of first and second generation technology roadmaps, whereas the organisational behaviour perspective is linked to the emergence of third generation technology roadmaps. These technology roadmap generations and various perspectives resulted in different definitions and formats of technology roadmaps as well as customised processes for their development.

It remains unclear which technology roadmapping generation and perspective best suits the innovation landscape at developing countries. Similarly, a simplistic multiple layered format of a generic technology roadmap format seems to be silent on some of the main factors that affect innovation in developing countries. Also with numerous processes that exist for technology roadmapping



exercise, it remains unclear which process is suitable for the developing countries.

2.3 Strategic importance of emerging technologies

Emerging technologies are known to inspire new changes to established industries by bringing new forms of competitiveness. This is achieved through improved process or product-technology, as well as improved knowledge intensive services. New process technology can bring about improved labour productivity, cost saving and economies of scale (Bogliacino & Pianta, 2011). This may lead to lower manufacturing costs and improved profitability. Product innovation inspired by emerging technologies results in products that exhibit new functionalities which can help to grow current markets and penetrate untapped markets.

These technologies have applications that need to be understood well in advance before their disruption to the current industries take effect. In addition to technological uncertainty, there exists also political and resource availability uncertainty (Meijer, Hekkert & Koppenjan, 2007) as the new emerging technologies may be prone to compete with the established technologies at firm level and prioritised industries at the macro level. Emerging technologies have an uncertain impact on the broader role players such as firms, markets, policymakers and society at large (Hu, Hung & Gao, 2011).

2.3.1 Characteristics of emerging technologies

Emerging technologies exist in various forms and can be found in various sectors, industries and organisations. They are mainly thought to be disruptive, although this is not always the case as they can also sustain existing product platforms or industries. The disruptive emerging technologies are defined as new technologies that have relatively low costs and performance as defined by traditional industry standards (Utterback & Akee, 2005). As shown in Figure 2.8, disruptive technologies typically result in products that are less sophisticated but

which appeal to the mainstream market that is neglected by the incumbents in favour of the most profitable high end of the market.

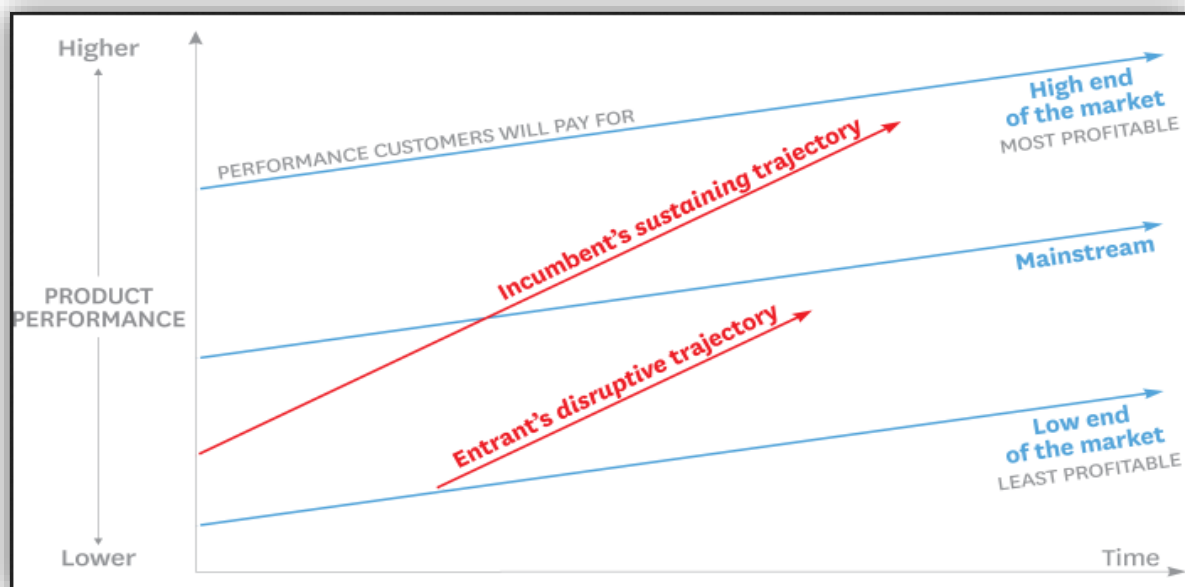


Figure 2.8: difference between disruptive and sustaining innovations

Source: Christensen, Raynor & McDonald (2015)

According to Kostoff, Boylan & Simons (2004), the products or services resulting from disruptive technologies are typically:

- smaller;
- lighter;
- cheaper;
- more flexible;
- convenient;
- more reliable;
- more efficient in terms of higher unit performance; and
- operationally simple.

Disruptive technologies have a high ancillary impact and their success depends on changing market expectation, government policy, etc. According to Walsh, Kirchhoff & Newbert (2002), a large return on investment for disruptive



technologies can take a very long time to realise in comparison to sustaining emerging technologies that are more incremental. Sustaining emerging technologies are likely to be applied to existing product platforms or industries in a relatively short period.

Emerging technologies can also be categorised in terms of being radical or incremental. The incremental technologies embrace the standard model of innovation, thus complementing the existing product-technology platforms and/or industries. The design of this type of technologies results from a continuous process of checking with the intended users of the product-technology platform (Norman & Verganti, 2014).

Radical emerging technologies often pose a challenge to incumbent firms as they employ knowledge-base that is new. Dahlin & Dehrens (2005) proposed the three criteria that should be met in order to classify emerging technologies as radical, namely: (i) novelty, (ii) uniqueness and (iii) impact on future technology. According to these authors, the first two criteria allow for identification of radical inventions prior to their introduction to the market. A last criterion serves to evaluate if the new invention served as an important change agent following its introduction to the market. If the timing is right and there is sufficient absorptive capacity within a firm, such radical innovations can improve the market competitiveness of existing or new product/ service platforms.

Emerging technologies can also be single or multiple. In case of multiple emerging technologies, they can compete or complement each other. Altmann et al. (2004) define converging emerging technologies as “enabling technologies and knowledge systems that enable each other in the pursuit of a common goal”. This definition is more aligned to converging emerging technologies that complement each other. In some cases such as electricity generation, multiple emerging technologies can compete with each other, especially in cases where there is technical and policy uncertainty as shown from a study by Rennkamp & Bhuyan (2016).



2.3.2 Industrial impact of emerging technologies

The widely known impact of emerging technologies is their disruption to incumbent firms. According to Ferriani, Garnsey & Probert (2008), breakthrough innovations are likely to be introduced by new market entrants as opposed to large firms that tend to experience inertia due to the competency trap. There are various reasons why the incumbent firms fail to efficiently adopt radical technologies. Some of these reasons, according to Chandy & Tellis (2000) are (i) perceived smaller incentives to introduce radical product innovations due to significant profits being received from current technology, (ii) presence of organisational filters that drive incumbents' existing market success by focusing on proven core capabilities and (iii) organisational routines that are geared toward effective development of incremental innovations that are based on current technology.

New entrants and small companies successfully embrace disruptive technologies as they have no existing revenue streams from product portfolio based on current technology and there are less formal organisational filters as well as established organisational routines.

Several strategies have been used by large firms to successfully respond to emerging disruptive technologies taking into account a competency trap. A common successful strategy is that of creating an innovating organisation that is separate from the operating organisation (Pati, 1999). For the innovating organisation to be successful, it needs to be protected by the top management from established organisational bureaucracies and standards that might hinder innovation. A classic case study is that of Teradyne, a semiconductor equipment manufacturer in which top management realised the possibility of complementary metal-oxide semiconductor (CMOS) chip technology disrupting the company's core business (Christensen, 1997). As CMOS technology could not meet high performance standards of current market of that time, a separate



innovating unit was created to champion the development of this CMOS chip technology.

Many scholars have done extensive research on the use of technology roadmaps in forecasting the emerging technologies that have potential to shape the industry in the near, medium and long term future (Walsh, 2004; Holmes & Ferrill, 2005; Phaal et al., 2011). The work by Phaal et al. (2011) used the past industrial dynamics to propose a framework for mapping industrial emergence. This framework incorporates the three main elements compatible with the technology roadmapping principle, viz.: phases and transition of industrial emergence (industry life cycle approach); thematic representation of industrial emergence (science, technology, products and markets); and significant events and milestones that characterise the industrial emergence.

2.3.3 Fourth industrial revolution

In a context of an increasing computing power and the endeavour of humans to solve complex problems, the digital evolution encompasses the increasing interaction between computing technology and the physical world (Wagenaar & Adami, 2004). This evolution has been building momentum long ago from the focus on artificial intelligence and autonomous robotic fields. According to Brooks (1991), the main goal of artificial intelligence at its conception was to enable the machines to replicate the human intelligence. The technical complexities associated with artificial intelligence grand challenge reduced most efforts to sub-fields such as natural language processing, computer vision, motion planning, robotics, automation, human assistants, driverless cars, smart cities, smart factories, etc.

Digital evolution is positively being embraced by businesses which seek to compete through smart processes and efficiency. Typically, digital innovation for businesses involves an ecosystem which comprises a large number of co-creators through modular architectures and high potential adopters (Venkatraman et al., 2014). In terms of modes of industrial production, digital



evolution has been coined the Fourth Industrial Revolution, which succeeds the Third Revolution that used electronics and information technology to automate (Schwab, 2015). The Second Industrial Revolution made use of electric power to achieve mass production, whereas the First Industrial Revolution mechanised production through the use of water and steam. As the Fourth Industrial Revolution involves convergence of various technologies such as ICT, nanotechnology, biotechnology, additive manufacturing and so on, a dialogue and consensus become vital among these stakeholders in addition to government, private fund managers, universities, etc.

According to Maynard (2015), foresight tools such as scenario planning and real-time technology assessment provide a solid foundation for guiding the Fourth Industrial Revolution towards the beneficial futures. Maynard points to an urgent need for a new generation of foresight capabilities that responds to converging emerging technologies that are being more sophisticated, diffusing rapidly, nonlinear and having tightly coupled trajectories. In the midst of all this complexity, technology roadmapping becomes an ideal technology assessment and a planning tool. It has the ability to bring together diverse stakeholders in an effort to integrate corporate, products and technology planning at a firm, industry or country level.

At the moment, there is a shortage of studies that integrates technology roadmapping methodology with the Fourth Industrial Revolution. At the application level, there are few roadmaps being formulated to take advantage of digital evolution, an example being the European Roadmap for Industrial Process Automation. This roadmap seeks to make use of emerging technologies such as automation, ICT and Internet of Things (IoT) to enable the European industries such as Mining & Minerals to achieve a predetermined set of objectives, namely: safety and security; distributed production; competence and quality of work; sustainability; productivity, platforms, products and services; machine to machine communication and human-machine interface (Lingman et al., 2013). However, this roadmap would be difficult to implement by developing



countries as it focuses purely on technical transition (research and development opportunities) and it neglects critical macro factors such as impact on jobs, culture of innovation, entrepreneurship culture, etc.

2.3.4 Summary of literature about emerging technologies

Table 2.1 summarises the main categories of emerging technologies and potential implications for technology roadmaps that incorporate these technologies as summarised from elements of the literature.

Table 2.1: emerging technologies and technology roadmaps

Types of Emerging Technologies	Characteristics	Implications for Technology Roadmapping
Disruptive vs Sustaining	Products targeted towards main stream (neglected) market versus those targeted towards high end (profitable) market	Disruptive emerging technologies require longer planning periods and a more conducive innovation ecosystem to establish innovation value chain (West, Vanhaverbeke & Chesbrough, 2006) 1 st generation technology roadmapping is more ideal for sustaining emerging technologies versus 2 nd generation roadmapping which is suitable for disruptive emerging technologies (Walsh, 2004; Tierney, Hermina & Walsh, 2013)
Incremental vs Radical	Technologies that complement existing product-technology platforms versus novel technologies that stretches the existing technological capability (competency)	1 st generation technology roadmapping more ideal for incremental emerging technologies (Tierney, Hermina & Walsh, 2013) versus 2 nd generation roadmapping which is suitable for radical emerging technologies (Walsh, 2004) Roadmapping of radical emerging technologies requires consideration of organisational innovation due to a change management required to transition to new competencies or core organisational capabilities (Cowan, 2013)
Single vs Multiple	Single root technology versus multiple converging root technologies	3 rd generation technology roadmapping is more ideal for multiple emerging technologies (Giasolli et al., 2014) Fourth industrial revolution necessitate further development of 3 rd generation technology roadmapping technique



It should be clear that the 1st and 2nd generation technology roadmaps are dominantly used to respond to single root emerging technologies that might be incremental, radical, disruptive or sustaining. The emergence of multiple root technologies, mainly through a phenomenon known as fourth industrial revolution, requires further development of 3rd generation technology roadmapping techniques in terms of roadmap format, roadmapping process and the implementation of the resulting technology roadmap.

2.4 Technology management in developing countries

In a context of an increasing globalisation and integrated global trade, the global value-chain literature is an ideal starting point in analysing technology management in developing countries. The innovation capability development theory by design is intertwined with value-chain upgrading theories (Qi et al., 2014). For developing countries, social and organisational innovations are worth exploring due to various societal and institutional challenges faced by these countries. The emergence of third generation technology roadmapping techniques is inspired by these types of complexities (Tierney, Hermina & Walsh, 2013).

2.4.1 Innovation management within a global value-chain

Developing countries are known to be the net importers of technology and high-technology products in terms of trade balance. A persistent and sticky challenge that is well known is low levels of productivity (Lingela, Buys & Shimozawa, 2007) that go along with high production costs, lack of key skills and lack of access to capital (Bartelsman & Doms, 2000). According to Bartelsman & Doms (2000), aggregate productivity at a firm level is influenced by the factors that can be controlled by a firm (innovation activity, input choices and outputs) but also by market interactions such as type of competition and market shares.

Within the scope of technology roadmapping, these competitiveness challenges faced by developing countries are analysed through the use of a value-chain framework and the literature relating to the upgrading of the value delivery



system. Kaplinsky & Morris (2001) define value-chain as “the full range of activities which are required to bring a product or a service from conception, through the different phases of production, delivery to consumers and disposal”.

In value-chain literature, the global value-chain analysis that studies power relationships and information asymmetry between lead firms and other firms such as those in developing countries (Trienekens, 2011) partially explains the productivity challenges and cost drivers that hamper innovation in developing countries. An important issue of significance is a concept of value-chain governance, which is based on the fact that few lead firms in global value-chain set and/ or enforce the parameters under which others in the chain operate (Humphrey & Schmitz, 2002). According to the authors, some value-chain aspects that are controlled by these lead suppliers are market access, fast track of production capability acquisition, support for host country policy initiatives and technical assistance. Global value-chain governance has co-evolutionary characteristics due to continuous adjustments and changes (Pietrobelli & Rabellotti, 2011).

Kaplinsky and Morris (2001) view value-chains as “repositories for rent which result from possession of scarce competitive resources and creation of the barriers to their access”. These barriers create superficial scarcity which results in super returns for innovations of lead firms. The economic rent is explained by Kaplinsky & Morris (2001) as arising from differential productivity of factors (including entrepreneurship) and barriers to entry (scarcity); as relational rents arising from purposeful activities taking place between groups of firms; and in terms of its various forms such as technological capabilities, organisational capabilities, skills and marketing capabilities. Royalties and licenses on patents, franchises, trademarks and industrial designs are all typical examples of economic rent.

According to Humphrey & Schmitz (2002), an increasing number of developing country producers engage in contract manufacturing as brands play a key role



in purchase decisions of the customers. Increasing contract manufacturing trends result from the fact that a success in technological innovation depends on consumer acceptance.

For firms in developing countries to overcome their challenges within the vicious cycle characterised by lack of entrepreneurship, lack of innovation, lack of productivity, lack of skills, etc., they need to upgrade their participation in global innovation value-chains to establish a new sustainable equilibrium. Various scholars have investigated mechanisms for value-chain upgrade in developing countries (Humphrey & Schmitz, 2002; Kaplinsky et al., 2003; Gereffi & Sturgeon, 2013). Such frameworks for value-chain upgrading unfortunately are in a form of being compliant to the demanding technology, production and product standards of the lead suppliers, rather than on developing countries' firms being equal partners within the global value-chain.

Humphrey & Schmitz (2002) discuss four types of value-chain upgrading, namely: (i) process upgrading, (ii) product upgrading, (iii) functional upgrading and (iv) intersectoral upgrading. Process upgrading involves transformation of inputs to outputs more efficiently by reorganising a production system or by introducing superior technology. Product upgrading entails a shift into more sophisticated product lines whereas functional upgrading takes place when firms acquire new functions or abandon existing functions so that they increase the overall skill content of their activities. Lastly, intersectoral upgrading takes place when firms apply competencies acquired in a specific function of a value-chain to move into a new sector.

Kaplinsky et al. (2003) applied these four value-chain upgrading trajectories on the global wood furniture value-chain, an industry that is mainly driven by the buyers. This work focused on key initiatives which the producers in developing countries need to do in order to upgrade their activities. Some findings of this work include issues such as blocking of producers within a footwear sector by global buyers from moving into more profitable activities such as design and



branding. On the contrary, these global buyers fully support the growth of producers' manufacturing capability.

According to Zamora (2016), buyer-driven value-chains are common in labour-intensive, consumer goods industries where large retailers, merchandisers and trading companies play a central role in establishing production networks, especially within the developing countries. Producer-driven value-chains are characterised by capital intensive and technologically oriented industries dominated by large multinational corporations (MNCs) which play a key role in managing the production networks (Abecassis-Moedas, 2006).

Some industrial policies that can be useful to facilitate access to global value-chains include lessening of a burden for international transportation of goods, customs clearance and distribution within the importing countries (Gereffi & Sturgeon, 2013). These policy interventions according to the authors should generally be aimed at reducing costs, delivery times and uncertainty. According to Gereffi (2013:446), a modern-day global value-chain oriented industrial policy focuses to a greater extent on the "intersection of global and local actors, and it takes the interests, power, and reach of lead firms and global suppliers into account, accepts international business networks as the appropriate field of play, and responds to pressures from international non-governmental organisations".

2.4.2 Innovation capacity development

The global value chain literature highlights various issues of interest regarding development of innovation capacity in developing countries. Through globalisation, the national innovation systems of different countries are interlinked and it is almost impossible to think of such a system without considering the strong exogenous factors, such as international finance and trade, having the greatest influence on the system.



De Marchi, Giuliani & Rabelotti (2015) observed that in order to understand how firms involved in global value chains innovate, scholars should not focus entirely on global value chain characteristics and the role of lead firms, instead they should take into account domestic technological capabilities at the firm, industrial cluster/regional and local innovation system-levels. Bell (2007) noted that in developing countries most innovation is based on non-R&D activities which consist of operationalising technology that is new to the situation of application. Such activities can involve product or process adaptation aimed at converting the acquired technology to be in line with the local market needs.

Some of the factors that hamper innovation and technological capability development in developing countries are low levels of educational attainment, complex business environment and underdeveloped information infrastructure (Aubert, 2005). According to the author, during the preindustrial phase the required educational level is at basic literacy, although for the industrial phase more professional and medium-level skills are required. Some additional institutional barriers that affect innovation in developing countries are (i) competition fairness, (ii) access to finance, (iii) laws and regulations, (iv) tax burden and (v) support systems (Zhu, Wittmann & Peng, 2012).

There are various frameworks for innovation capacity development. As for example, Kocoglu et al. (2012) investigated factors that promote technological learning and the main focus was on complementary learning, manufacturing and R&D capabilities. These are thought as a critical foundation of a systemic innovation strategy through the establishment of appropriate routines, accumulation of internal skills and development of the ability to learn selectively.

R&D capabilities enable the organisations to assimilate knowledge from external sources, but also for novel inventions (Shan & Jolly, 2012). The impact of existing manufacturing capability to technological innovation capacity can be explained in terms of a concept of technological distance. Gilsing et al. (2008) arrived at a conclusion that a large technological distance has a negative effect



on absorptive capacity, although this can have a positive effect on the potential for novelty creation.

In developing countries, technological learning can also be achieved through technology transfer from developed countries. Some of the mechanisms that exist to effect such technology transfer are foreign direct investment (FDI) and intellectual property (IP) exchange through trade in embodied and disembodied technologies. FDI has been instrumental in technology transfer from MNCs to developing countries in East Asian countries such as China (Lew & Liu, 2016). On the contrary, South Korea chose to rely less on the FDI and instead it encouraged domestic firms to build extensive global networks, with foreign firms providing technology via licensing, capital goods and original equipment manufacturers' contracts (Urata & Lall, 2003).

The East Asia's contradictory experience with regard to the role of FDI in technology transfer from developed countries can be reconciled through the observation that with either cases foreign technological know-how played a significant role in local technological capability development. There are various policy frameworks that can be used by governments in developing countries to accelerate technology transfer into their countries. According to Hoekman, Maskus & Saggi (2005), these national policies range from economy-wide programmes such as improvement of education levels to funding for the creation and acquisition of technology, tax incentives for purchase of capital equipment and favourable intellectual property rights (IPRs) regime.

In some instances, the regulatory reforms become necessary in developing countries to enable technological innovation and to remove the obstacles that are stifling innovation. There exist various forms of government regulations in areas such as environment, safety, health, competition, IPRs, land usage, labour, etc. These regulations differ per country as they can be prescriptive or performance-based. According to Ford, Steen & Verreyne (2014), prescriptive



regulations which are more 'command and control' type are shown to support incremental innovations.

Therefore, for emerging technologies deregulation or performance-based regulations are more favourable options as shown by the case of Uber, a company that is increasingly becoming a poster-child for anti-regulation (Isaac, 2014). It has been argued in the literature that innovation should precede regulation (Harriss-White & Rodrigo, 2013), a typical exception being environmental technology innovations which are typically nurtured by environmental regulations (Farrell et al., 2003). In some instances, escape clauses can be used within regulations to enable innovation through emerging technologies.

2.5 Chapter summary and gap analysis

Due to a potential low innovation capability at developing countries, it follows that most developing countries lack their own product-technology platforms, relying more on technology transfer from developed countries. This has the advantage of the minimised competency trap that is experienced mostly by innovation leaders who have an established core capabilities (Chandy & Tellis, 2000). The first generation technology roadmaps might not be suitable for developing countries that aspire to adopt a drastic technology catch-up strategy as these are based on a stable product technology platform (Tierney, Hermina & Walsh, 2013).

On the other hand, first generation technology roadmaps are likely to attract the much needed support and resources for the incumbents. This challenge also presents itself on the choice of emerging technologies that can be useful for innovation capability upgrading at developing countries. Whereas the disruptive and radical emerging technologies give opportunity for developing countries to create their niche innovation areas (Thoma & O'Sullivan, 2011), the main challenge becomes access to the global innovation value chain, which has certain established governance standards.



There exists a gap in terms of the choice of an appropriate technology roadmapping framework for developing countries, both for the purpose of innovation capability upgrading and in terms of the need to respond to the challenges and opportunities brought by fourth industrial revolution. Clear innovation pathways are in need for the innovation landscape of developing countries that has complex macro factors that have direct and indirect influence on innovation (Li et al., 2016).

The next chapter uses the emerging perspectives out of the literature review to inductively develop a technology roadmapping framework for developing countries. Furthermore, this critical literature informs a choice of research methodology (chapter 4).

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CHAPTER 3: CONCEPTUAL FRAMEWORK FOR TECHNOLOGY ROADMAP DEVELOPMENT IN DEVELOPING COUNTRIES

3.1 Introduction

The complex environment of developing countries, explained in some detail in section 2.4, calls for a technology roadmapping framework that takes into account challenges such as lack of innovation and entrepreneurship capacity, policy uncertainty and the less integrated market. Various scholars (Berger, 2001; Kaggwa, Steyn & Pouris, 2017) investigated a wide range of technology management frameworks which are ideal for these complex environments and one of the most relevant is complex systems. As technology roadmaps are concerned with future market and technology perspectives (Phaal, Farrukh & Probert, 2004), innovation catch-up strategies and technology leapfrogging theories are relevant in building a technology roadmapping framework for developing countries. Transition management theory is relevant in defining a framework for a fundamental shift from an undesired innovation state to a desired state (McDowall, 2012).

The main objective of this chapter is to link these various theories with existing technology roadmapping theory, on roadmapping process and format, in order to derive a technology roadmapping framework which is ideal for developing countries. This also takes into account an in-depth literature review in chapter 2, namely: the evolution of technology roadmaps, the strategic importance of emerging technologies and technology management in developing countries. The convergence of multiple emerging technologies, the difficulty in upgrading to the high-level hierarchy of the global innovation value-chain by firms in developing countries and the emergence of the third generation technology roadmaps necessitate a thorough understanding of the complexity of innovation systems in developing countries through a complex system theory and the use of transition management and technology leapfrogging theories for technology and market long-range planning.



3.2 Multilevel analysis perspective of complex innovation systems

There are various definitions of complex systems which are associated with its various branches. For example, from a mathematical point of view, in a nonlinear dynamic system theory, it is defined as “a system whose total energy exceeds the threshold to operate within the realm of classical mechanics but does not reach a threshold to exhibit chaotic properties” (Hassani, Asgari & Lee, 2015:1).

In systems theory, it is defined as “a system with numerous components and interconnections, interactions or interdependencies that are difficult to describe, understand, predict, manage, design, and/or change” (Magee & de Weck, 2004). According to Shiell, Hawe & Gold (2008), a complex system is adaptive to changes in its local environment, it is composed of other complex sub-systems and it behaves in non-linear fashion such that a change in the outcome is not necessarily proportional to a change in input.

Some characteristics of complex systems are emergent properties that are observed at the system level, but not at its individual parts (Choi, Dooley & Rungtusanatham, 2001); and have adaptive and dynamic behaviour that maintains a stable equilibrium state through resistance and resilience (Limburg et al., 2002). Lucas (2000) described some complex system characteristics which were later grouped by Bertelsen (2003) as composed of autonomous parts with certain behaviours (non-standard, co-evolutionary, self-modification, downward causation and self-reproduction) and in terms of non-linearity (emergence, multiple alternative attractors, phase changes and unpredictability).

Multi-level perspective theory depicted in Figure 3.1 has been used to analyse complex innovation systems. In this framework, the novel configurations are generated at the niche innovation level, which depends on an established regime at the meso-level and the innovation landscape at the macro-level (Geels, 2002). It should be noted that in this model no central agent at macro, meso or micro level can unilaterally determine the outcomes of the innovation

system as established innovators/ regime can be influenced by disruptive innovations from niche innovators or by changes in the innovation landscape. A key assumption for the purpose of this study is the fact that most developing countries' innovating organisations are on the niche innovation level, at the periphery of leading global innovators (Trienekens , 2011).

The multi-level framework is important for technology roadmapping in developing countries as the dominant technology roadmapping literature is based on the needs of incumbents to respond to future market needs and to protect themselves against current and future competitors, e.g. the Motorola Technology Roadmap (Willyard & McLees, 1987).

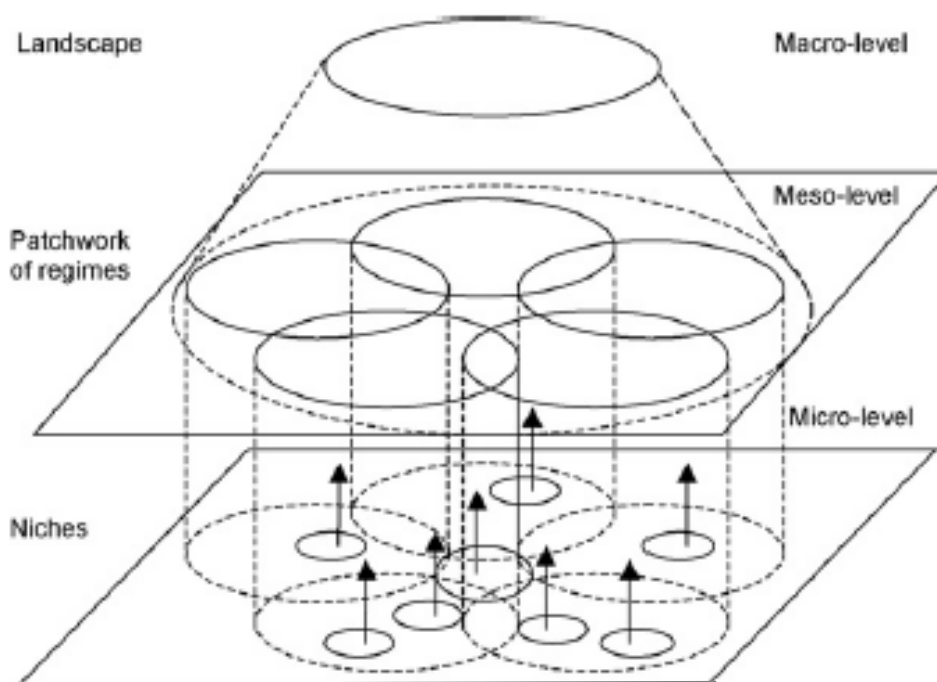


Figure 3.1: multi-level analysis framework

Source: Genus & Coles (2008)

According to the findings of the study commissioned in 2003 by the Dutch Ministry of Economic Affairs on 78 technology roadmapping initiatives, one of the best practices is to launch the technology roadmapping activities within an existing 'social infrastructure' (Phaal, Farrukh & Probert, 2010). For niche



innovators, especially those with disruptive innovations, such 'social infrastructure' might not exist and it might need to be built from scratch.

3.3 Leapfrogging as a technology catch-up strategy

Technology leapfrogging assumes skipping of industrialisation trajectories followed by developed countries and to leapfrog directly into a new innovation regime as part of new capacity addition. According to Perkins (2003), in order to achieve leapfrogging, the following conditions need to be met: i) a shift towards new sustainable production approaches, ii) an action from the outset, iii) technology transfer from developed economies, iv) strengthening of the incentive regime and v) international assistance.

Rubio & Folchi (2012) have shown leapfrogging to be instrumental in allowing a set of follower economies to reach the next rung of sustainable productions 30 years in advance of the most developed economies. Leapfrogging can enable developing countries to be significant innovative role players on established global markets, but also on the new markets created by the shifting innovation landscape. A fourth industrial revolution, global economic recession and climate mitigation are among several megatrends that shape the global innovation landscape. According to Wu, Ma & Shi (2010:52), "the phenomena of technological paradigm shifts open a window of opportunity for latecomer firms to realise technological leapfrogging by importing emerging technologies from developed countries".

The blue ocean strategic management perspective introduced by Kim & Mauborgne (2004) is one possibility of technology leapfrogging through servicing the neglected market or societal need. This catch-up strategy involves avoidance of competition in overcrowded industries, also called red oceans, in which the products/ services get more expensive as competitors invest hugely to outclass each other. With a blue ocean strategy, the competition is irrelevant as niche innovators focus their efforts on uncontested and neglected markets.



3.4 Transition management theory

Transition management theory is of particular interest for technology planning in developing countries as it provides a framework for leapfrogging of their innovation systems. The transition of complex systems takes place at the multilevel, which includes niche innovations, sociotechnical regimes and sociotechnical landscapes; hence successful transitions are a result of interactions among these three levels (Geels & Schot, 2007). Transition based strategies and policies are aimed at stepping away from incremental developments along 'business-as-usual' trajectories (Voß, Smith & Grin, 2009) by inducing and guiding complex processes of sociotechnical change by means of deliberation, probing and learning.

As transition management involves changes on sociotechnical systems from an established paradigm to the new one, innovation management in this context needs to be based on both technological innovation as well as social innovation. Social innovation, according to Humphreys & Guaipatin (2014) is defined as new solutions to challenges faced by people whose needs the market does not meet, and that has a positive impact on society. They must be carried out through an inclusive process, incorporating the beneficiaries (people) to adequately define the problem, and employing public–private–people partnerships towards the development of the solution.

Transition and complex system theories' concepts have been applied briefly to technology roadmapping literature by several scholars such as Phaal, Farrukh & Probert (2004); Vojak & Chambers (2004); and Tierney, Hermina & Walsh (2013). The innovation process is getting more complex as shown by the sixth generation innovation model, which is also called an open innovation model (Stefanovska Ceravolo & Polenakovik, 2016), hence these theories are useful for both developing and developed countries. While developing countries' interests are in nurturing the niche innovations for upscaling, the firms in



developed countries would like to prepare themselves for potential technology transitions driven by factors such as disruptive technologies.

3.5 Proposed technology roadmap format for developing countries

A simplistic, generic technology roadmap output format has been the reason for increasing wide popularity in using the technology roadmapping techniques in long range technology planning. However, for complex innovation systems in need of transition from poor global competitiveness to mainstream innovation, there are other key issues that need to be incorporated into the technology roadmapping format as shown in Figure 3.2.

The technology roadmapping format proposed in this study is derived from Genus and Coles (2008) and it incorporates key transition management phases on the horizontal axis. These key components of transition as articulated by van der Brugge, Rotmans & Loorbach (2005) are predevelopment of innovation niches, take-off, acceleration and stabilisation phases. These resemble the life cycle phases of development, introduction, growth and maturity. During the predevelopment phase, networks and partnerships are important. Technology sources can either be in-house or outsourced and the same goes for manufacturing capability. This phase communicates to the stakeholders the innovation niches that will be experimented in order to derive the knowledge of what works and what does not work.

The niche innovations are shown along with the dominant innovation value-chain within the industry or globally in order to benchmark and to deduce plausible future technological paths in business-as-usual environment. A parallel roadmapping effort that also considers the dominant innovation value-chain is useful for technology planning purposes based on the fact that this represents the best available product technology platform preferred by customers prior to the transition point. In the initial version of a technology roadmap, an emergent innovation value-chain can represent the ideal emergent innovation standards that are necessary to effect a successful transition.

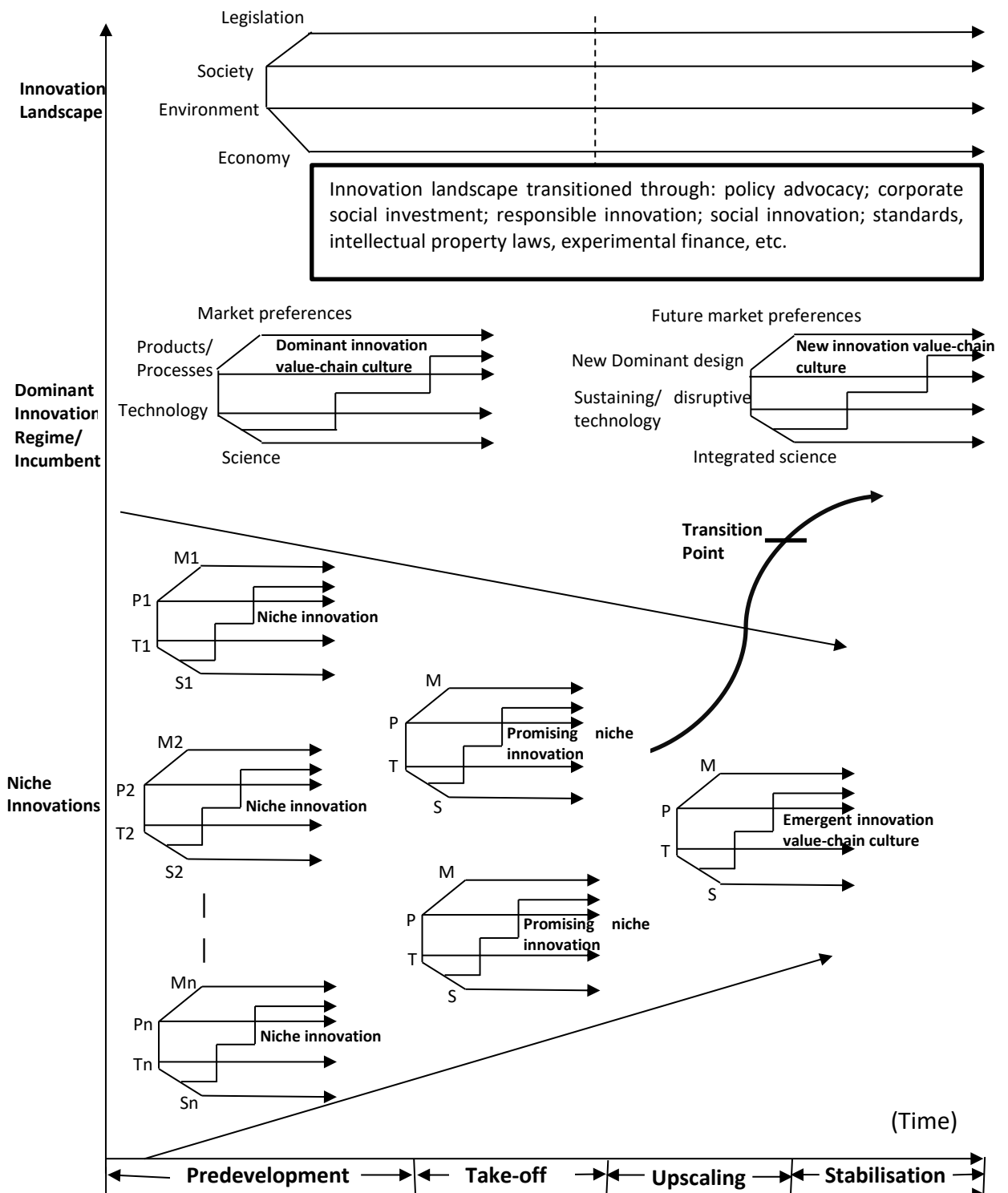


Figure 3.2: format for roadmapping complex innovation systems

Source: adapted from Genus & Coles (2008)



From the knowledge gained during the predevelopment phase, this roadmap can be updated for the take-off and transition phases. The transition point is where the transition takes place during the acceleration phase. Foresighting of the innovation landscape components (legislation, society, environment and economy) can inform the dynamics that will take place in the future between the emergent innovation value-chain in comparison to the dominant innovation value-chain.

3.6 Proposed technology roadmapping process for developing countries

The technology roadmapping framework for developing countries is developed with a generic technology roadmapping process proposed by Garcia & Bray (1997) as a starting point (Figure 3.3). This approach was followed by various scholars in customising the technology roadmapping process (Han et al., 2012).

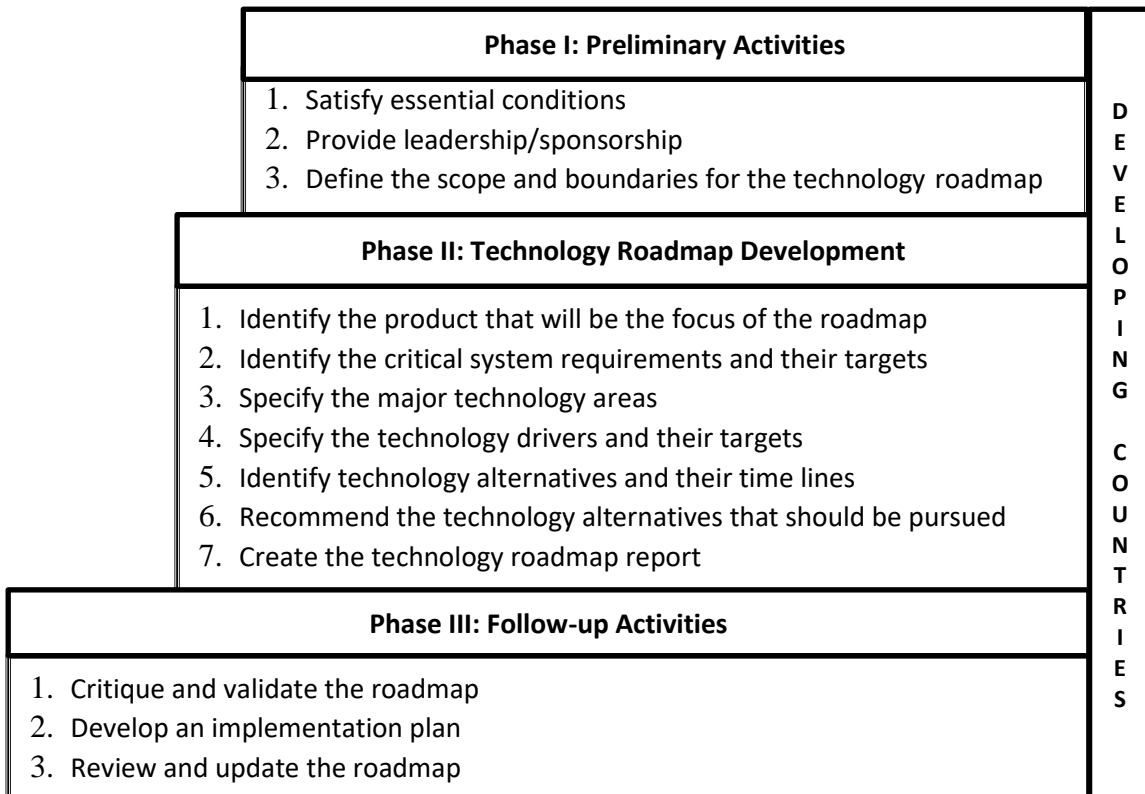


Figure 3.3: the three phases for technology roadmapping process

Source: adapted from Garcia & Bray (1997)



This process has three main phases, namely: (i) the preliminary activities, (ii) technology roadmap development and (iii) follow-up activities.

Even though Walsh (2004) recognised that a traditional technology roadmapping approach is not suitable for a disruptive technology roadmapping process, a key observation is the fact that there is nothing wrong with the utilisation of technology roadmapping techniques, but rather with a blind application of these techniques in cases such as a disruptive technology base.

To address this concern, the proposed framework for technology roadmapping in developing countries in this study takes into account existing theoretical frameworks such as complex systems and transition management to reflect developing countries' innovation environments.

The technology roadmapping process that is aimed at transitioning very complex innovation systems, such as those in developing countries, is a complex issue on its own. The format that is presented in Figure 3.2 simply summarises an outcome of the roadmap and there are vast amounts of analyses, discussions and workshops that need to take place prior to that to achieve this consolidated vision. As noted by Phaal, Farrukh & Probert (2004:5), "technology roadmaps are deceptively simple in terms of format, but their development poses significant challenges".

The generic technology roadmapping framework is used as a frame of reference to define key activities that need to take place prior to the roadmapping effort (preliminary activities), during the development of the technology roadmap and post roadmapping. A modified technology roadmapping methodology for disruptive technologies contained within Walsh (2004) has ideal concepts for roadmapping in developing countries' environment where there is a scarcity of a stable product-technology platform based on unique innovation capabilities.



3.6.1 Preliminary activities

The essential requirements for a technology roadmapping effort involve issues such as making sure that there is a sufficient perceived need for a technology roadmap and to ensure participation from a broad range of stakeholders within the innovation value-chain that brings different perspectives to this process (Garcia & Bray, 1997). The complexity of market, products and technology decisions required in developing countries' environment implies the need to have a very knowledgeable group of stakeholder experts and seasoned practitioners in support of a roadmapping exercise. A key decision to be made by the roadmapping facilitators/ committee is a balance between partners that are heavily invested in the current dominant product technology platform and those that are more flexible in moving towards a new dominant platform.

According to Voß, Smith & Grin (2009), transition management efforts tend to be vulnerable towards capture by powerful incumbents of the status quo. At an organisational level, employees need to be actively involved in the development of technology roadmaps as according to Brah & Hunsucker (2000), their participation promotes creativity, innovation and commitment to the transition.

As an example, a change from an efficiency-driven to innovation-driven paradigm poses a threat to the prevailing success metrics such as productivity and returns on capital which might cloud a potential sociotechnical transition. This is likely to be a case for the developing countries in which there are established practices such as reliance on imported technologies. The decisions on a choice of stakeholders for technology roadmapping also apply in providing leadership and sponsorship for the technology roadmapping effort.

In order for this process to be successful in developing countries, sufficient effort needs to be made to ensure adoption of a knowledge-based culture which allows the necessary conditions for experimentation and learning (Zack, 2003). As it is a case for most technology roadmaps, there should be a roadmapping committee that is responsible to oversee initial technology roadmap



development; to monitor niche innovations, evolution of innovation landscape and that of the current sociotechnical regime; and to lead selection and upscaling of promising niche innovations through an update of the roadmap.

A choice of transition management and complex systems theories for the purpose of this technology roadmapping framework partially explains the scope and boundaries on technology roadmap development for developing countries. The vision is to migrate from the provision of subsystems, to full systems and eventually to full customer solutions; at the country level to transition from technology import driven economy to a net exporter of technology; and at an industrial level to achieve the new breakthroughs in terms of products, processes and technology in order to compete successfully nationally and within the global value-chain.

Once this vision for transition and a move away from business-as-usual activities are clearly articulated, there may be a high probability for consensus and a shared outlook on the future. Since the transition period is around 20 - 25 years (Voß, Smith & Grin, 2009), the time horizon on developing countries' technology roadmaps need to be relatively long for a successful transition.

3.6.2 Technology roadmap development

The first step in technology roadmap development is the identification of a product that would be a focus of the roadmapping effort. This step has some level of complexity, especially for complex innovations, an example being that for disruptive technologies. Walsh (2004) articulated on this complexity, in which there is no dominant product technology platform that exists. Instead the author suggests identification of promising product technology platforms and identification of grand challenges. These candidate product technology paradigms form part of the niche innovations shown in Figure 3.2, of which their roadmapping needs to be in parallel to that of dominant innovation value-chain regime, an exercise similar to benchmarking.



As it was introduced in section 3.3, Kim & Mauborgne (2005) use the concepts of 'red oceans' and 'blue oceans' strategies in describing a choice of products focusing on current and future industries respectively. A strategy canvas is introduced by the authors and this maps opportunities resulting from a gap between dominant product/ services offered and customer needs. The benefit of this blue ocean strategy is reduction in production costs and increased customer value, hence a strategy that has large potential if adopted by developing countries.

At the national technology policy level, there are two policy choices that a developing country's government can adopt to promote technical change, namely: accumulation and assimilation interventions. Lall & Teubal (1998) state that an experience from East Asian countries shows assimilation based interventions to be quite successful as they emphasise the significance of learning in making public and private investments successful. Accumulation theories assume a sufficient investment in human and physical capital will automatically bring about technical change, and typical indicators that are widely followed are Gross Expenditure on Research and Development (GERD) and number of researchers per labour force.

This technology roadmapping framework is based on assimilation theories, in which according to Lall & Teubal (1998), they can take the form of selectivity (picking winners), functionality (interventions intended to improve factor markets without favouring particular activities) and horizontal interventions that lie between selective and functional interventions. In a selective policy environment, niche innovations need to prove themselves as a viable alternative in order to be supported by the government for upscaling.

The horizontal technology policies (HTPs) according to Teubal (1997) are central to government inducement of technology-based structural change, including those countries with scant pre-existing capacity to identify strategic niche innovations or strategic technologies. According to the author, an objective



of HTPs is functional promotion of socially desirable technological activities and associated management and organisational routines within business enterprises.

In identifying major technology areas, technology drivers and technology alternatives, emerging technologies in a form of disruptive or sustaining technologies are more appealing to the developing countries. These technologies are key for firms and industries within the developing countries to transition them from niche innovations to mainstream global innovation value-chain as they carry less burden of economic rent through IP licensing and payment of royalty fees.

Emerging technologies that sustain the current product technology platform are more likely to attract resources, although there is a high likelihood that there will be an acquisition bid from dominant market leaders to acquire such technologies before large scale innovation can be realised. A good example is an internet consulting business in South Africa, Thwate, which became one of the first companies to be recognised by Netscape and Microsoft “as a trusted third party for web site certification” (Smuts, 2008:1). According to the author, VeriSign later acquired the IP from Thwate at a price tag of \$575 million.

The technology roadmap report in a context of developing countries still serves a purpose of identification and description of candidate products and technology areas; assessment of current technological capacity; identification of critical factors that, if not met, will cause the roadmapping effort to fail; technical recommendations; and implementation recommendations. The main difference is a greater need for constant update of the assumptions contained within the roadmap as more learning takes place and the innovation landscape becomes more predictable.



3.6.3 Follow-up activities

Part of technology roadmapping validation is to secure a buy-in from the critical stakeholders, even the majority of those deeply entrenched on a current dominant product technology platform. Their critique and validation of technology roadmaps is useful in addressing possible risks and to fine tune the assumptions contained within the roadmap.

The transition management theory for complex innovation systems advocates for learning-by-doing and doing-by-learning (Farrelly & Brown, 2011), hence the implementation plan resulting from the developed technology roadmap(s) needs to have a high degree of flexibility to adapt to the changes in innovation landscape and for the possible response by the incumbents. More importantly, this flexibility allows for a change of priorities as more information becomes available.

The technology roadmaps need frequent reviews and updates in order to stay relevant. The transition based technology roadmaps as shown in Figure 3.2 have certain transition stages that need these reviews and updates prior to large investments or key decisions. A key critical point is between predevelopment and upscaling stages where the decisions need to be made about niche innovations that need upscaling. The roadmapping framework contained within Walsh (2004) introduces another step as part of the technology roadmap review and update, namely: seeking of transition timing to the new innovation value-chain culture.

3.7 Chapter summary

The technology roadmapping process and format for developing countries which is proposed in this chapter seems to be ideal to address the complexities encountered with regard to the innovation planning in technology catch-up situations. As opposed to the reductionist approaches that are based on conducive environments for innovation, the approach selected recognises developing countries' complex interactions that are taking place at systemic



level, but also aligns well with the 6th generation innovation model that is based on knowledge and connectivity. In a traditional technology roadmapping approach, the innovation landscape is compressed on a market layer in a vertical scale of a generic technology roadmapping format. The suggested technology roadmap format achieves a goal of networked and knowledge based organisation by providing information on broad innovation landscape components, future prospective of the current incumbents and the alternative futures for niche innovations.

The roadmapping approach suggested doesn't explicitly state how the workshops and different consensus seeking discussions should be conducted as it only lays the foundation of key issues for consideration during the roadmapping exercise for developing countries' environments. This framework is enhanced further in chapters 5 and 6, through the research methodology developed in chapter 4.

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CHAPTER 4: RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

The methodology adopted for this research responds to the research questions that were identified in this study. The first research question is about the identification of unique framework conditions for innovation in developing countries whereas the second question is whether technology roadmapping practices and literature can be adapted for these innovation framework conditions in developing countries.

This section is also informed by the theoretical framework developed and a detailed literature review presented in the preceding chapters. It explains and motivates reasons why the research design is adopted and why the methodology and data collection techniques are used. In addition, a discussion about the limitations of the study and ethical considerations follows.

4.2 Research design

The type of research philosophy adopted directly influences the choice of research approach and the research strategy to be used. The research strategy is also influenced by the availability and type of data at the disposal of the researcher. This section shows how this research was carried out systematically using accepted research best practices in order to arrive at logical conclusions.

4.2.1 Research philosophy and approach

The research methodologists long observed that a specific research philosophy being followed often reflects the researcher's mental view of the experimental setup being studied (Bambale, 2014). The three known research philosophical stances are typically (i) positivism, (ii) interpretivism and (iii) realism. The core principle of a positivism research perspective is based on the assumption that the researcher is detached from a phenomenon being investigated (Coghlan & Brannick, 2014) and the research is conducted scientifically in a manner that



there are elements of replicability, objectivity and detailed observation (Mayer, 1992).

The positivism perspective would neither be suitable for investigation of innovation dynamics in developing countries nor for deduction of appropriate technology roadmapping frameworks for these complex environments. Innovation is a nonlinear, complex process within a complex system (Ghinoi, 2016) which often takes place in multiple pathways. The same successful innovation strategy in one company or a country can give different results if it is applied somewhere else, otherwise all organisations and countries could easily become the innovation champions.

The complex technology roadmapping framework proposed for developing countries also incorporates issues such as complex systems theory and sociotechnical transition of complex innovation systems. Replicability is not a norm for technology roadmapping frameworks as demonstrated by the variety of their customisation (Lee & Park, 2005; Phaal, Farrukh & Probert, 2001), depending on the context of the technological area being roadmapped.

The philosophy adopted for this research is a realism perspective due to the complex nature of technology roadmaps being investigated. According to Saunders, Philip & Thornhill (2003:84), a realism perspective is based on the belief that “a reality exists that is independent of human thoughts and beliefs”. This reality is shaped by broader social forces, structures or processes such as innovation framework conditions and competition. These factors shape how various actors view and interact with the world around them.

The technology roadmapping theoretical framework proposed in chapter 3 incorporates a multilevel analysis perspective for complex innovation systems. A complex system is a system that consists of a large number of interacting elements and whose global behaviour cannot be simply inferred from the behaviours of the single elements (Piegari, Di Maio & Scandone, 2013). By design, a technology roadmapping exercise applies collaborative realism in



forming consensus about a common future (McCarthy, Haley & Dixon, 2001). According to Phaal, Farrukh & Probert (2004), the technology roadmap structure and the process leading to its development are flexible as they can be adapted to suit various technological and strategic situations.

This research combines both deductive and inductive approaches in a sense that there is a theoretical framework developed, although it would be complex to use a finite working model to test the propositions on technology roadmap process and format for developing countries. The inductive approach therefore was also used to enhance this theoretical framework. Hence a mixed research approach is followed in a form of quantitative survey, qualitative interviews, secondary data and analysis of case technology roadmaps in order to draw perspectives about sociotechnical transitions taking place and the implications for technology roadmapping approach within developing countries' environment.

Mixed research method approaches have been used broadly and their various forms as well as advantages are discussed within a literature review paper by Gunasekare (2015). According to this review, there are two main types of mixed research approaches, namely: mixed method research and mixed model research. Mixed method research, which is used in this study, is a "research in which the researcher uses the qualitative research paradigm for one phase of a research study and the quantitative research paradigm for another phase of the study" (Gunasekare, 2015:362).

Schulenberg (2007) articulates in detail the situations that necessitate the use of a mixed method approach, namely: (i) if there are questions that can best be addressed through qualitative research while others could be addressed through quantitative research; (ii) if questions that can be answered through qualitative research are analysed through a grounded theory approach; (iii) if there are questions that can be analysed both quantitatively and qualitatively using qualitative data; and (iv) if there are questions that can be analysed both quantitatively and qualitatively in which each data source address separate

theoretical propositions. The usage of a mixed method approach in this research can be explained through both (i) and (iv).

4.2.2 Population and data access issues

This study was targeted at practitioners and technology roadmapping experts in South Africa. As illustrated in Figure 4.1, these potential respondents can hail from various functional areas such as corporate, production, systems integration, technology development or R&D.

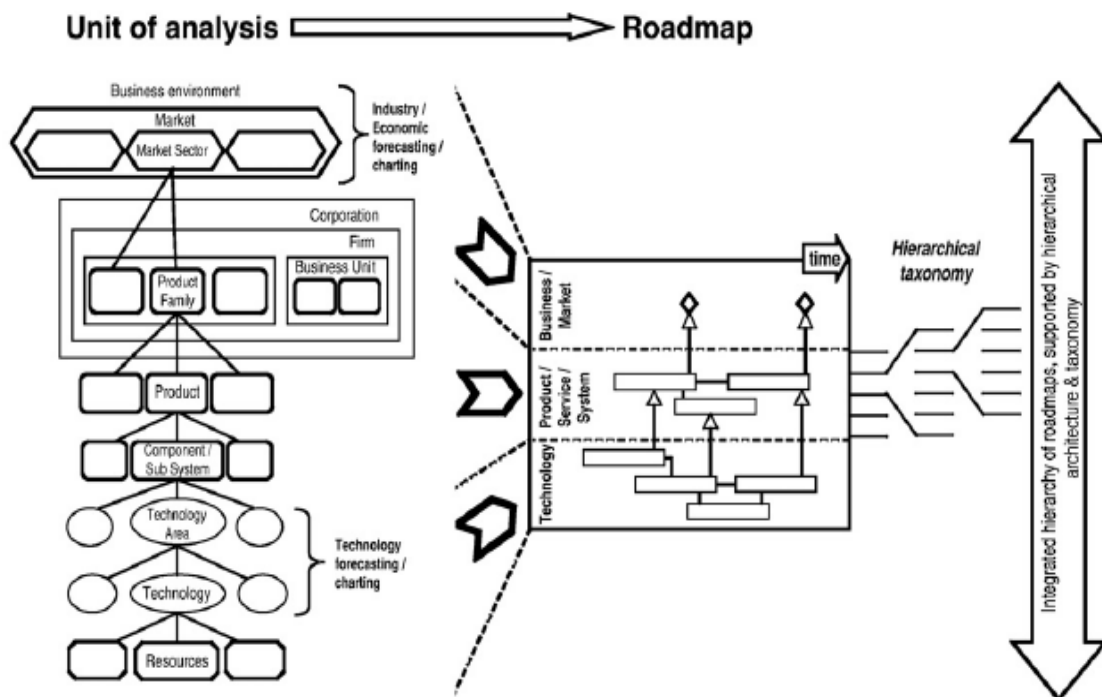


Figure 4.1: technology roadmaps and organisational unit of analysis

Source: Phaal & Muller (2009)

The technology roadmapping community also represents diverse institutions such as the business sector, government, research institutions, higher education sector and civic not-for-profit organisations (NPOs). Furthermore, another unit of analysis is economic sectors in which technology roadmaps are focused towards.



As technology roadmaps are the strategic lens into the innovation dynamics taking place (Phaal & Muller, 2009), identification of innovation framework conditions in South Africa is from the perspective of the technology roadmapping community, an important issue that has influence on inferences out of this research.

In terms of data access issues, it was much easier to access public sector technology roadmaps. Most of these roadmaps show a list of participants, a technology roadmapping committee (if any) and experts used for the development of the technology roadmap. The main challenge was access or even knowledge about potential technology roadmapping activities taking place in the private sector. A challenge of a 'hidden population' is well documented in the literature. According to Heckathorn (1997:174), a population is 'hidden' "when no sampling frame exists and public acknowledgment of membership in the population is potentially threatening".

The strategy used to facilitate access to respondents from this sector involved a web search, literature search and scanning of social media platforms such as LinkedIn. The information contained on social media had to be validated and cleaned as it might not always be complete or correct (Weller, 2015). However, social media is a valuable source of accurate information about the organisation, its structure and the factors that characterise social reach of their employees (Bozzon et al., 2014).

Unfortunately, most of the respondents obtained through social media platforms, mainly LinkedIn, were involved with software technology roadmaps that are short term in nature and most of these potential respondents didn't understand the topic being investigated. Software technology roadmaps typically has a planning horizon of 2-3 years (Phaal & Muller, 2009) whereas technology roadmaps in general are used for long-range planning in which the future is uncertain. According to Kappel (2001), a long-range plan for technology



roadmaps spans a period of more than three years. Hence the potential respondents from the software industry were excluded from this research.

4.3 Quantitative survey

This section addresses issues concerned with sampling, questionnaire design and administration of an online questionnaire. This quantitative survey was aimed at addressing the research questions for this study and it was informed by literature review and the proposed conceptual framework for technology roadmapping in developing countries.

4.3.1 Sampling for quantitative survey

In the context of a very small/ 'hidden' technology roadmapping community in South Africa, the initial sample consisted of approximately 105 respondents (Table 4.1). Based on preliminary information collected, these respondents had taken part on technology roadmapping initiatives from different sectors such as government, state owned enterprises, large companies, SMEs, NPOs and higher education institutions. The majority of these respondents had taken part on technology roadmapping initiatives which were led by the state owned enterprises (54.3%) followed by government (31.4%). Due to a small or even uncertain technology roadmapping community in South Africa to work with, a purposive sampling technique was used to select an initial list of potential respondents. This non-probabilistic sampling technique involves a deliberate choice of participants due to the qualities they possess (Etikan, Musa & Alkassim, 2016). According to Heckathorn (1997), sampling procedures that are typically used for 'hidden populations' include snowball and other chain-referral samples, key informant approach and targeted sampling.

About 44 valid and seven invalid responses were received while eight respondents couldn't be reached. Therefore an adjusted survey response rate is calculated as follows:



$$\text{Adjusted Survey Response Rate} = \left(\frac{44}{105-7-8} \right) * 100\% = 49\%$$

Table 4.1: sample for potential technology roadmapping respondents

Sector for Technology Roadmapping Institution	Number of Potential Respondents	% of Total Potential Respondents
Government	33	31.4
Government Agency/ Enterprise	57	54.3
Large Companies	6	5.7
SMEs	1	1.0
NPOs	2	1.9
Higher Education Institutions	6	5.7
Total	105	100

Table 4.2 summarises a list of responses received. The table includes new categories of technology roadmapping institutions such as industry associations as well as international organisations in and outside of South Africa.

Table 4.2: responses received per sector of technology roadmapping organisation

Sector for Technology Roadmapping Institution	Number of Respondents	% of Total Respondents
Government	18	45.0
State Owned Enterprises	15	37.5
Large Companies	13	32.5
SMEs	8	20.0
NPOs	5	12.5
Higher Education Institutions	4	10.0
Industry Associations	9	22.5
International Organisation in South Africa	7	17.5
International Organisation Outside of South Africa	8	20.0
Science Councils	18	45.0
All Sectors	44	100

The notable difference between Table 4.1 and 4.2 is a large number of the responses received from large companies, SMEs and NPOs in comparison to



the initial sample. There are many explanations that can explain this observation. Firstly, the potential respondents in Table 4.1 are categorised according to the information available to the researcher at the time of sampling. The respondents were allowed to reclassify themselves as they complete a questionnaire. Secondly, an online questionnaire was used for the survey and this might attract the respondents that were not on an initial sample. The advantages and disadvantages of online questionnaire are discussed in sub-section 4.3.2.

The proportion of respondents who participated in technology roadmaps for large companies is 32.5% and that for SMEs is 20.0%. These numbers are very large compared to information collected from initial sample screening. This is unsurprising as it has already been alluded about the secretive nature of company technology roadmaps.

Since this research is concerned with technology roadmapping activities within South Africa, at first glance, there will be a concern about 20.0% of respondents who took part on technology roadmaps developed by organisations outside of South Africa. Fortunately, these respondents indicated that they also participated on technology roadmaps developed in South Africa. Their international experience in fact is valuable in reflecting on the unique challenges for technology roadmapping in South Africa.

4.3.2 Questionnaire design

A quantitative survey was designed with a clear purpose of making sure that it is easy and clear to complete, but also to ensure that it is fit-for-purpose. As shown by a questionnaire contained in Appendix A (A.4), certain critical questions marked with an asterisk (*) were made compulsory to complete in order to address the research questions. The other complementary questions were still important, although it was important to remove any rigidity as much as possible in order to accommodate various respondents who might not have enough time to address all survey questions. According to Kelley et al. (2003),



a well-designed research tool is simple, appropriate for the intended use and acceptable to the respondents. A slight variation on the number of questions completed by the respondents was taken into account during data analysis.

A final questionnaire was improved through feedback received from the pilot survey that was conducted with the assistance of staff at the CSIR. About 12 respondents took part in this pilot survey, which necessitated expansion of the selection list of some of the questions and minor modification on structuring of some of the questions. Overall, there was no significant difference between a questionnaire used for the pilot survey and the modified final questionnaire, hence the initial responses received during the pilot phase were incorporated into the final pool of responses.

According to van Teijlingen & Hundley (2002), the advantage of conducting a pilot study is that of getting warning in advance on areas where the main research project might fail, where research protocol might not be followed or on whether the proposed research methods or instruments are appropriate in answering the research questions.

An online quantitative survey was conducted with researchers and practitioners involved with the technology roadmaps development in South Africa. With a limited sample of potential respondents, this survey tool enabled ability to reach efficiently various respondents at different parts of the country. As observed by Wright (2005), online surveys can save researchers time by allowing them to work on other tasks while collecting data at the same time, although respondents occasionally requested technical support in completing the questionnaire. Live analysis and summary of responses through this online platform also allowed for rapid analysis of pilot survey data and identification of the areas for improvement on the questionnaire.

Online surveys, however, have challenges inherent within them. According to Wright (2005), one of such challenges concerns sample control issues. As this survey was shared through a web link with potential respondents, this link could



have easily fallen into invalid respondents which are outside of a target population. To address this issue, this online question clearly stated the objective of the study and a question was asked if the participants have experience or ever participated in long-range strategic planning exercise in which future technology requirements are matched to the products/ market needs. If the respondent answers no, they could no longer be able to complete the remaining questions. However, there were very few responses that were invalidated because they completed only a few initial questions on general information.

4.4 Qualitative interviews and desktop study

Qualitative research was designed to probe some of the in-depth issues that needed detailed probing. These included areas such as sociotechnical interactions between the innovation landscape, niche innovators and the incumbents. This technique was also used as a follow-up to some of the findings of quantitative survey that didn't show a clear logic or contradicted theoretical positions on the literature. For the same purpose, a desktop study was conducted for content analysis of selected case technology roadmaps in order to triangulate the information received from the quantitative survey.

4.4.1 Qualitative research sampling

As was the case with regard to non-probabilistic targeted sampling used for quantitative survey, a targeted purposive sample was selected in preparation for qualitative interviews. A total of 13 respondents who were mainly senior managers were interviewed, using various communication platforms. As stated in previous sections, the technology roadmapping process brings together diverse stakeholders who might not be familiar with the entire roadmapping exercise.

Some of technology roadmap development participants might have attended selected roadmapping workshops that are targeted to focus areas such as technology selection and/ or capability analysis. Hence it was important to



engage senior personnel that might have played a role as technology roadmap consultant, sponsors or those who sit on technology roadmapping committees. Another set of targeted respondents are officials from standards setting bodies and competition authorities.

According to Meyer & Booker (2001), the researcher can use the experts' information to make inferences where data do not exist or where data is sparse. A sample was selected such that it incorporates the respondents from the innovation landscape (e.g. government and competition authority), incumbents and niche innovators.

4.4.2 Qualitative interviews protocol

Qualitative research was conducted using various communication platforms such as face-to-face interviews, telephonic interview and email interview. According to Dutton, Duque & Hunsinger (2007), internet-based interviews such as chats and emails are cost effective methodological tools with global reach and these platforms are useful for professional respondents with a reliable internet access. The telephonic qualitative interview technique has been used extensively by various scholars (e.g. Sangsanoi-Terkchareon, 2015; Sharma et al., 2010; Govindarajo & Kumar, 2013). Both telephonic and email interviews are recommended to be used in situations where the social cues of the researcher are not important, especially when dealing with respondents who are providing an expert opinion (Opdenakker, 2006).

In case of face-to-face interviews, the questions were sent to the respondents beforehand at least two days before the day of the interview in order to make sure that they are prepared and they have familiarised themselves with the questions. The duration of these semi-structured qualitative interviews were between 30 and 60 minutes. The respondents were asked to sign the informed consent form prior to the interview (Appendix A, A.2).



In all these types of qualitative interviews, prior reading was done on technology roadmapping activity that the respondent might have taken part in. According to Cutcliffe (2000), prior reading may be required in circumstances where the researcher needs to clarify concepts and build an emergent theory on these. As stated, an inductive approach is also used for this research in order to enhance the technology roadmapping framework for developing countries.

4.5 Data analysis procedure

The research questions in this study are primarily addressed through data collected from the online survey. A primary goal of quantitative data analysis in this study is to draw patterns about innovation dynamics and technology roadmapping practice in South Africa. According to McEvoy & Richards (2006), the strength of quantitative methods during an exploratory phase of research is in identifying patterns and associations that may otherwise be masked. For this research, qualitative data in most instances is not reported separately, but instead used to enhance interpretation and synthesis of concepts emerging out of quantitative data.

In this post-positivism critical realism research approach, both qualitative and quantitative data analysis is aimed at understanding complex framework conditions shaping technology roadmapping in developing countries. Quantitative survey data is used for empirical investigation of the proposed technology roadmapping framework whereas qualitative survey data is used for further theory building through in-depth interpretation of emerging concepts.

Document analysis was also done from the publicly available technology roadmap documents in South Africa to derive the key innovation landscape drivers that affect innovation in the country or firm level. The use of secondary data in addition to the primary data is useful for triangulation of results and to ensure their validity. Analysis of qualitative data is combined with document analysis to determine the nature of sociotechnical transitions taking place for selected case technology roadmaps.



4.6 Ethical considerations

This research was conducted in adherence to strict ethical considerations in order to maintain respondents' dignity and to prevent any harm to them. Ethical consideration is an important component of research, especially where there are human subjects involved. Technology roadmaps contains sensitive information about how companies visualise and respond to the market and technology futures. Hence it was important to assure the respondents about protection of their identities. It is widely known that technology is an important strategic asset for many organisations (Arman, Hodgson & Gindy, 2006).

A standard ethical clearance procedure of the Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria's was adhered to. This involved securing of ethics approval (Appendix A) before any data could be collected. The respondents were asked to sign/ acknowledge their informed consent during both quantitative surveys and qualitative interviews. The permissions for conducting research were secured at several organisations as shown in Appendix A (A.1).

4.7 Chapter summary

The rationale and principles behind the choice of research methodologies have been presented in detail in this chapter. The realism research philosophy seems to be suitable for this type of research which uses the best of both the quantitative and qualitative research methodologies. This research philosophy also enables the combining of inductive and deductive research approaches. Since there is a challenge of a low sample and a 'hidden' population, the probabilistic research strategy would not be suitable. The research methodology adopted complement the innovation dynamics and technology roadmapping patterns derived through the quantitative survey with the qualitative data and documents analysis in order to strengthen the interpretation of these patterns. Such interpretations are externalised through the analytical propositions that are induced in chapters 5 and 6.



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CHAPTER 5: INNOVATION DYNAMICS IN SOUTH AFRICA AS A BASE FOR TECHNOLOGY ROADMAPPING

5.1 Introduction

This chapter addresses the first main research question regarding the unique framework conditions for innovation in developing countries, and South Africa is the focus of this study. The two specific research sub-questions being addressed for this main question are i) identification of priorities for innovation in South Africa, from the perspective of the technology roadmapping community, and ii) identification of actual/ perceived innovation competitive advantages for South Africa. Five propositions are generated drawing from the interpretation of data and the patterns observed out of quantitative survey data (Appendix B).

5.2 Priorities of innovation for the South African technology roadmapping community

The standard innovation value-chain is divided into three key stages, namely: idea generation, conversion and diffusion (Hansen & Birkinshaw, 2007). Idea generation can originate in-house, external or in collaboration between the organisation and its partners. Conversion entails ideas selection and further development of these ideas into technology platforms, viable products, businesses and best practices. Diffusion involves wide acceptance of these technologies, products, businesses and best practices across the organisation and by the targeted external recipients/ market.

As shown in Table B2 (Appendix B), the main priority of innovation for technology roadmaps developed in South Africa is technology development (70.5% of respondents), followed at a distance by basic and/ or applied research (45.5%). It can be deduced from Table B3 (Appendix B) that the likely impact of the innovation programmes that are part of South African technology roadmaps is the technological capability development (63.6%) followed by economic impact at country level (61.4%), research capability development (56.9%) and market competitiveness (54.5%).



Therefore, in triangulating data from Tables B2 and B3 (Appendix B) an inference can be drawn that South African technology roadmaps are developed mainly for the purpose of technological capability development followed by research capability development. S&T roadmaps have been documented extensively in the literature (Kajikawa et al., 2008; Kostoff & Schaller, 2001). According to Kajikawa et al. (2008), S&T roadmaps are a consensus articulation of scientifically informed vision of attractive technology futures. On the innovation value-chain spectrum, S&T roadmaps link idea generation with the conversion of these ideas to technologies, products and processes.

The innovation dynamic of South African S&T roadmaps is different in the sense that the focus is more on building future technological capability, starting from a weak baseline. As shown by Shin, Hong & Grupp (1999), based on experience from national foresight exercises, technology planning for underdeveloped and developing countries helps in defining the strategic direction for selective and indigenous S&T development in order to catch-up further economically and socially. This leads to the first deduced proposition:

Proposition 1: the main innovation priority for technology roadmaps in developing countries is science-driven technological capability development

The discussion about the generalisation to the other developing countries for this proposition and the preceding ones is in section 8.6. In order to strengthen the analytical generalisation developed in relation to proposition 1, the focus of South African technology roadmaps is tabulated by the technology roadmapping organisation and the target industry in Table B4 and B5 (Appendix B) respectively. In terms of technology roadmapping organisations, this generalisation about technological capability development applies to almost all the organisational types identified. The main issue for observation is the fact that most roadmapping organisations focus more on R&D agenda setting as a means to develop technology platforms.



The organisation types that focus mainly on R&D agenda setting as part of technology roadmaps development are international organisations in South Africa (100.0% of respondents), higher education institutions (100.0%), government (94.4%), science councils (88.9%), SMEs (87.5%), NPOs (80%), industry associations (77.8%), international organisations outside of South Africa (75%) and state owned enterprises (73.3%).

The notable exemptions to this observation are the large companies in which their roadmaps focus more towards technology platform development (69.2%) followed by product platform development (61.5%) as well as technology and market integration (61.5%). The only technology roadmapping organisation types that seem not to prioritise technology and market integration are higher education institutions (25.0% of respondents) and international organisations outside of South Africa (37.5%). The following proposition is deduced:

Proposition 2: the main innovation priority for technology roadmaps of private sector companies in developing countries is technology development and market integration

This analytical inference includes also the state owned enterprises as the only difference results from the fact that large companies focus more on technology platform development to respond to market needs, whereas the state owned enterprises focus more on R&D agenda setting as a means to integrate technology to the market. This proposition seems to be well aligned to the main technology roadmapping literature that define technology roadmaps as a strategic approach that is ideal to support the development, communication and implementation of technology and business strategy (Phaal, Farrukh & Probert, 2004). However, the notable difference is with regard to focus of private and public sector technology roadmaps.

According to Londo et al. (n.d.), whereas private sector technology roadmaps are predominantly concerned with technology diffusion (implementation and deployment), public sector technology roadmaps are primarily focused on R&D



and technology development. In developing countries, R&D agenda setting and technology development prioritisation of the public sector serve as enablers for innovation activities of the private sector (El Amine & Abderrezak, 2013).

An analysis of the technology roadmap's focus per the target industry in Table B5 (Appendix B) also confirms the government's focus on R&D agenda setting (70% of respondents) in order to develop technological capability. This is also a case for economic sectors that are dominated by government, such as electricity, water and gas supply. As the mining sector is dominated by large companies, technology roadmaps that are targeted towards this sector show characteristics of large companies' focus areas, namely: technology platform development (85.7% of respondents) as well as technology development and market integration (85.7%).

5.3 Innovation competitive advantage

The Schumpeterian economic theory is premised on the assumption that innovation competitive advantage strongly depends on economic agents such as entrepreneurs through a process of creative destruction (Tülüce & Yurtkur, 2015). The emphasis of this economic theory of growth is more on innovation competitiveness as opposed to price competitiveness. This section analyses factors that influence innovation in South Africa as well as the extent in which the country is embracing the opportunities that are presented by emerging technologies.

5.3.1 Positive and negative factors influencing innovation

In Figure 5.1, the main factors that influence the innovation programmes that are part of South African technology roadmaps are arranged in terms of innovation landscape, dominant innovation regime and niche innovations. The number of respondents and percentage of respondents are shown per each construct.



As Figure 5.1 shows, competitive advantage of innovation programmes that are part of technology roadmaps in South Africa is aligned mainly with the R&D capability (68.2% of respondents) followed by a strong network of partners within the innovation ecosystem (52.3%). As has been alluded by various scholars, R&D investment results with increased knowledge absorptive capacity and improved technology transfer for various organisations and the country as a whole (Berchicci, 2013; Schmidt, 2010; Grünfeld, 2003).

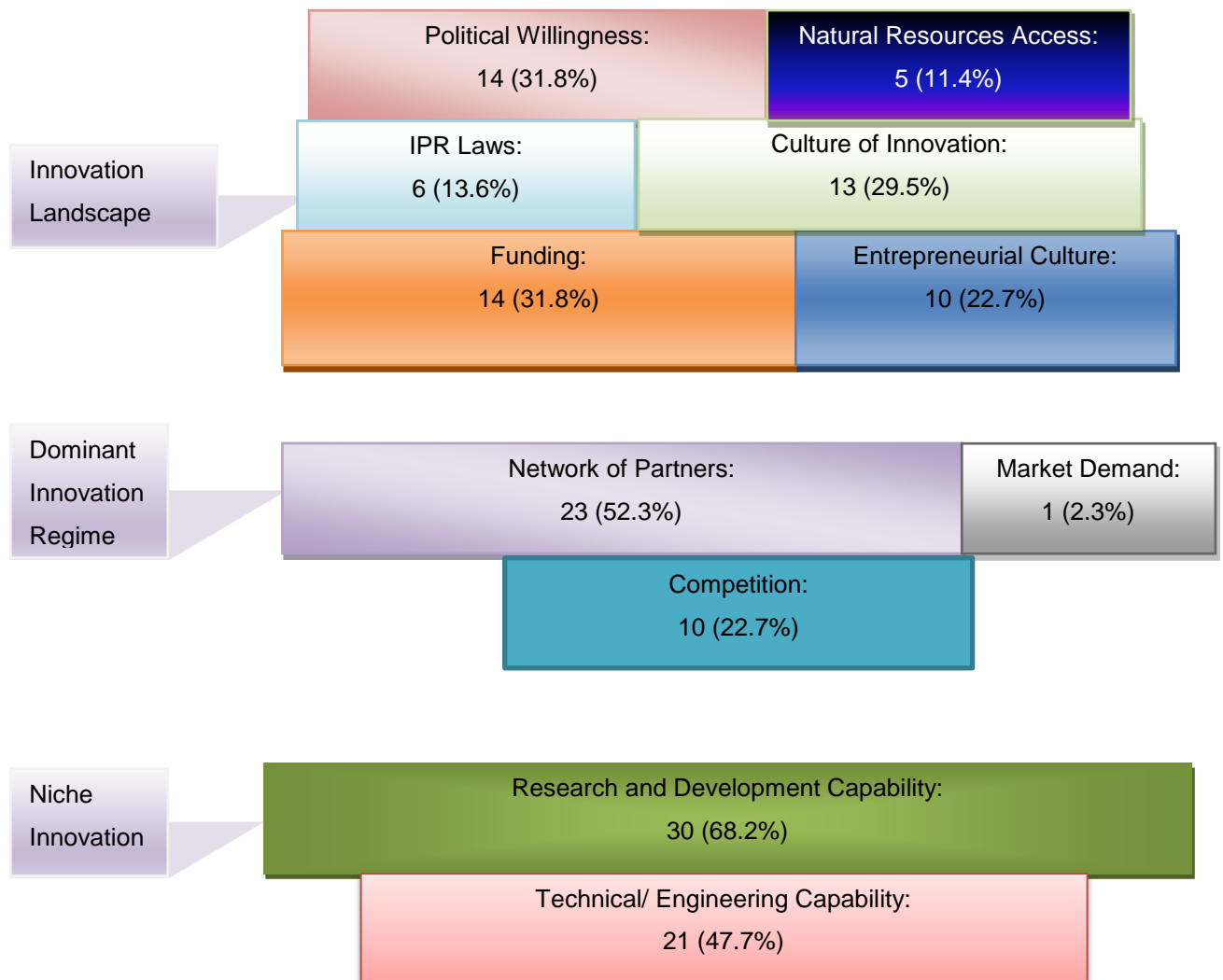


Figure 5.1: main factors that are positively influencing the innovation programmes of TRMs

Not all the organisations will perform R&D due to risks associated with it such as spillover effects and technical uncertainties. Hence, government typically



needs to invest in R&D at universities and other public research organisations with the aim of stimulating innovation in the private sector, mainly the SMMEs. R&D incentives are typically used to stimulate R&D investment by large companies (Atkinson, 2007).

Although the respondents mentioned R&D capability as the main innovation competitive advantage, gross R&D expenditure in South Africa at 0.80% of GDP is still very low in comparison to the Organisation of Economic Corporation and Development's average of 2.4%. R&D capability as competitive advantage is therefore in relation to other factors within the country, not necessarily in relation to the world. Another way of interpreting this stated competitive advantage is recognising the fact that technology roadmapping organisations in South Africa, such as science councils, are highly R&D intensive. A main purpose of their technology roadmaps is to convert the R&D outputs into technology platforms as summarised by proposition 1.

External networks of partners are important in the sense that they can be sources of ideas (Parida & Westerberg, 2007) for knowledge creation and also for technology platform development. To support this point, NACI (2014) has shown that South African researchers published about 84.1% of scientific papers in 2013 with at least one author from the top 10 collaborating countries around the world.

Furthermore, NACI (2016) shows an increase in non-residents patents registered from South Africa. As suggested by the experts, the source of these non-residents South African patents is MNCs operating within the country. Locally, R&D collaboration between science councils and universities is strong (NACI, 2015). This collaboration is also high between universities and the business sector, although there is a low R&D collaboration between science councils and universities.

The following proposition is deduced:



Proposition 3: external networks of partners are valuable sources of competitive advantage for innovation programmes that are part of technology roadmaps in developing countries

Figure 5.1 shows that a tangible proportion of respondents (47.7%) considered a technical/ engineering capability as one of the factors that positively influences the innovation programmes that are part of South African technology roadmaps. This concerns ‘technological distance’ issue that was discussed in-depth in section 2.4.2 of the literature review concerning the innovation capacity development. According to Bhaduri & Ray (2004:89), “it is generally argued that know-how-oriented technological learning (production engineering) enhances firm-level competitive advantage by augmenting production efficiency”. As it was the case with regard to R&D capabilities, South African engineering capabilities are still lacking as deduced from a low component of high-technology exports from the country. According to NACI (2016), South African high-technology exports as a percentage of all merchandise exports was only 4.01% in 2015, a slight increase from the value of 3.59% during 1996.

Figure 5.2 shows the factors that inhibit the innovation programmes that are part of South African technology roadmaps. Lack of funding is topping the list (72.7%) followed by lack of political willingness (52.3%) and lack of entrepreneurial culture (43.2%).

The funding issue comes as no surprise as GDP growth rates were 1.3% and 1.6% during 2015 and 2014 respectively. At the time of writing this document, South Africa was in technical economic recession. As one of the objectives of technology roadmaps is to commit the resources for the implementation of shared outlook of the technological future (McDowall, 2012), lack of funding can have a serious impact on the ability to implement a technology roadmap.

According to detailed elaboration by some of the quantitative survey respondents, lack of political willingness include issues such as policy flip-flop as demonstrated by the initial support of renewable energy but later support of



nuclear energy. Another dimension mentioned for unfavourable political climate in South Africa is political instability and corruption. Serfontein & de Waal (2015) mention the increase in reports of economic greediness, retrenchments, mismanagement and inefficient government as well as corruption.

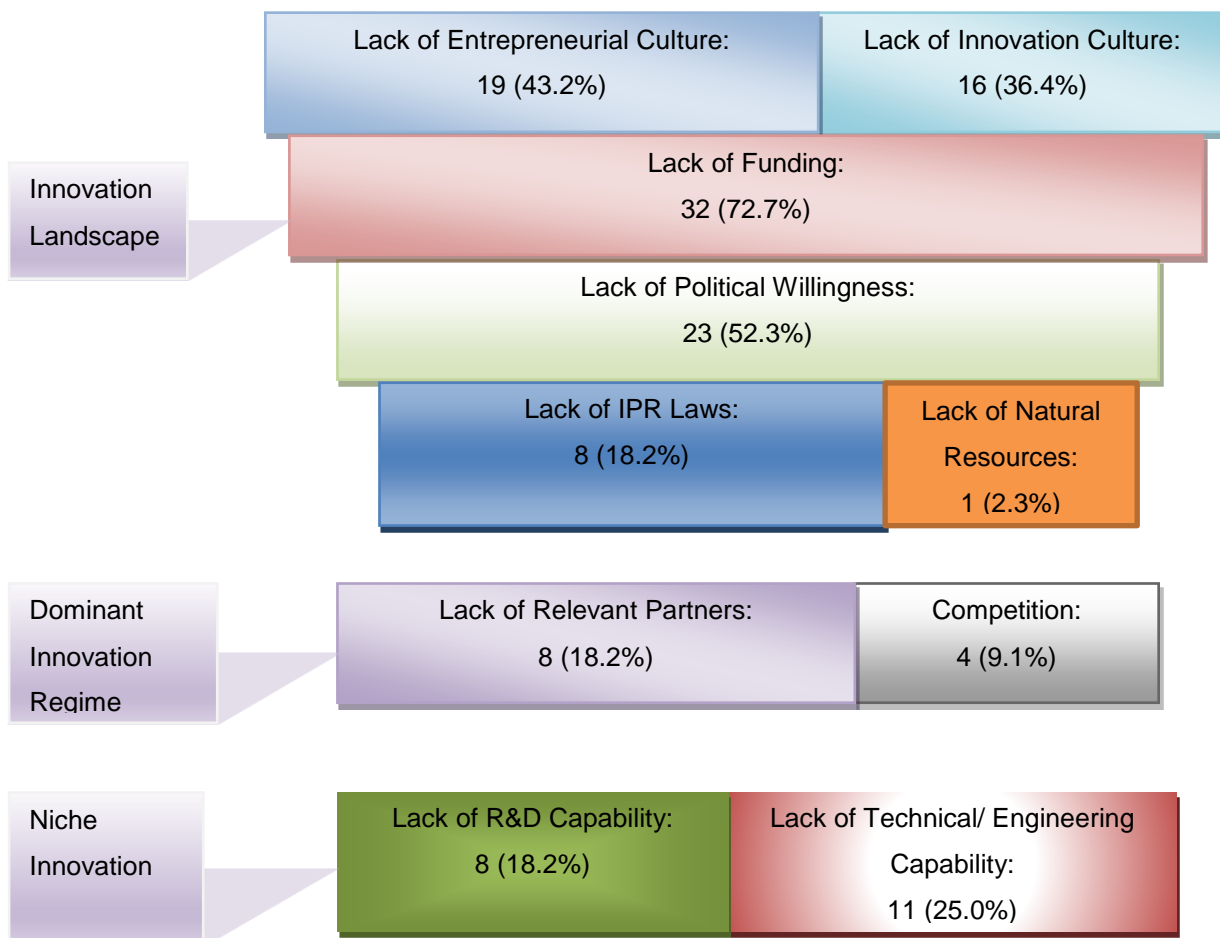


Figure 5.2: main factors that are negatively influencing the innovation programmes of TRMs

Both political instability or uncertainty and lack of funding are innovation competitive advantage inhibitors that might not last in the long-term. Although they need to be considered for development of technology roadmaps in South Africa, a window of opportunity for a positively changing innovation landscape needs to be determined for achievement of technology roadmap objectives. Political instability, lack of funding and lack of entrepreneurial and innovation



culture are predominant at developing countries' environment, such as that of South Africa.

This leads to the following proposition:

Proposition 4: timing of the innovation landscape's window of opportunity is important for technology roadmapping in developing countries in order to create the innovation competitive advantage

According to Cooper (2001), innovation success is highly dependent on the ability to accelerate product innovation, to get products to market ahead of the competition and within the window of opportunity. Proposition 4 is therefore about conversion of external threats to opportunities in order to create an innovation competitive advantage that might not be clear to the organisation's competitors. As explained by Perez & Soete (1988), innovation catching-up involves being in a position to take advantage of the window of opportunity temporarily created by technological transitions and the shifting innovation landscape.

Within technology roadmapping literature, this window of opportunity concept according to Walsh (2004) refers to seeking of transition timing to the new innovation value-chain culture. As indicated by Jeffrey, Sedgwick & Robinson (2013), a new form of roadmapping is evolving in which the roadmaps are used to persuade governments to implement or at least facilitate the implementation of actions and recommendations set out. Furthermore, Ogura (2016) recommends exploration of the development of a political roadmap along with a technical roadmap. As technology roadmapping organisations would not typically have a political mandate, such a political roadmap would be limited only at the advocacy and persuasion strategies.

5.3.2 Opportunities presented by emerging technologies

A recent window of opportunity is presented in a form of multiple emerging technologies through a concept called the fourth industrial revolution. As shown



by Table B6 (Appendix B), dominant emerging technologies that are part of technology roadmaps in South Africa are renewable energy technologies (48.8% of respondents) followed by IoT/ big data (37.2%).

According to Verbong & Geels (2007:1036), “ongoing regime developments do not yet provide a window of opportunity for wide uptake and diffusion of radical energy options”. This is applicable to the current energy innovation landscape in South Africa in which there is a policy and political uncertainty with regard to support of renewable energy adoption. The innovation landscape drivers that are more likely to open-up the window of opportunity for wider adoption of renewable energy technologies are climate change shocks and shifts in public opinion (Verbong & Geels, 2007). Climate change influence or target is incorporated into energy future scenarios of South Africa. According to a recently published government gazette (DOE, 2016), the four energy future scenarios that are part of the updated Integrated Resource Plan (IRP) for South Africa are:

- Base case: business-as-usual scenario.
- Resources constrained: high energy price scenario.
- Environmental awareness scenario.
- Greenshots: high economic growth scenario.

The most favourable scenarios for renewable energy niche innovators in South Africa are ‘resources constrained’ and ‘environmental awareness’ scenarios as the two open opportunities for renewable energies to flourish. The greenshots scenario also provides opportunities for renewable energy actors by virtue of high growth, although political willingness on issues such as deregulation of the energy sector, would play a major part in this scenario.

In terms of big data and IoT, the global innovation landscape’s window of opportunity opened recently through popularisation of the fourth industrial revolution concept at the 2016 World Economic Forum gathering which was held at Davos, Switzerland. This industrial revolution presents opportunities for



development of smart factories (Hermann, Pentek & Otto, 2016), smart cities (Boulos, Tsouros & Holopainen, 2015), autonomous mining, etc. The country-level innovation landscapes in South Africa and other developing countries are still deliberating on the possible impact of fourth industrial revolution and hence there is policy uncertainty around this issue.

As shown in Table B7 (Appendix B), the majority of emerging technologies that are part of technology roadmaps in South Africa are selected based on alignment to global trends as opposed to relevance to the country. The global trend is probably the industry 4.0. An exception is the renewable energy technologies which are mainly selected based on relevance to the country (76.2% of respondents). In terms of selection based on socioeconomic impact (societal and market needs), most emerging technologies are selected based on the market needs, an exception in this case being environmental technologies that are selected based on societal needs.

For emerging technologies such as aero structures, 3D/4D printing, photonics and robotics/ automation, there is a balance between selection based on R&D and engineering capabilities. These technologies form part of the advanced manufacturing category. R&D and engineering capabilities are intertwined for the advanced manufacturing sector. Selection of emerging technologies mainly based on R&D capabilities is done for biotechnology (55.6% of respondents), environmental technologies (50%), nanotechnology (54.5%) and renewable energy technologies (42.9%).

The following proposition is therefore deduced:

Proposition 5: novel innovation pathways are likely to result from technology roadmap innovation programmes that make use of biotechnology, nanotechnology and environmental technologies.

Ground-breaking novel innovation pathways can be the great source of competitiveness and technology catch-up for developing countries. Novel



nanotechnology innovations include intelligent weight management for consumers (Handford et al., 2014) as well as Nanobiotix technology and its role in cancer therapy (Num & Useh, 2013). These novel innovation pathways result in international market competitiveness and high profit margins (Handford et al., 2014).

The novelty of innovation pathways that make use of the three technologies mentioned on proposition 5 can clearly be demonstrated through Table B8 (Appendix B) in which it is clear that the expected impact of these emerging technologies is mainly new product development (NPD). Almost all the emerging technologies that are part of this study are aimed towards NPD. This strong focus on NPD indicates the presence of niche innovators who seek to disrupt existing products through the emerging technologies. As elaborated by Story, Boso & Cadogan (2015), innovativeness should encompass firms' proclivity to embrace creativity, novelty, and experimentation in NPD activities. In addition to NPD, there is a balance of expected emerging technologies' impact in terms of new industry creation, improvement of existing products and improvement of the current industry.

5.4 Chapter summary

The five deduced analytical propositions regarding the innovation dynamics in South Africa, as a case for developing countries, address the key issues to consider in transitioning the complex innovation systems. Both propositions 1 and 2 guide the agenda setting for technology roadmaps in developing countries in terms an inclination towards technological capability development and market integration. This shows the need for transition-based technology management frameworks for developing countries in order to upgrade their innovation capabilities to the global level. In order to achieve this transition, the public sector performs the role of innovation enabler whereas the private sector captures the value creating through the market competitiveness. The efficiency in which this



innovation vision can be realised is facilitated by the external network of partners as articulated through proposition 3.

Whereas proposition 4 recognises the timing of window of opportunities presented by the shifting innovation landscape and the dynamics taking place between the niche innovators and the incumbents, proposition 5 indicates one such opportunity presented by the emerging technologies such as biotechnology, nanotechnology and environmental technologies. The convergence of these technologies along with digitisation and big data forms part of the fourth industrial revolution. Chapter 6 will show how these innovation dynamics influence the nature and characteristics of technology roadmaps in developing countries.

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CHAPTER 6: TECHNOLOGY ROADMAPS IN SOUTH AFRICA

6.1 Introduction

The main research question being addressed in this chapter is whether existing technology roadmapping practice can be adapted for developing countries' framework conditions. The analytical inferences are deduced on areas concerning the nature and characteristics of technology roadmaps in developing countries as well as the factors that are critical for success of these technology roadmaps.

6.2 Nature and characteristics of technology roadmaps

As shown by Phaal, Farrukh & Probert (2004), various types of technology roadmaps can be distinguished in terms of purpose, format and usage. An analysis of innovation dynamics in the previous chapter revealed the purpose of South African technology roadmaps to be that of technological capability development through activities such as R&D agenda setting. This section probes further into the nature and characteristic of technology roadmaps in South Africa.

6.2.1 Technology roadmap generations

The discussion in the literature review about technology roadmapping generations and types of emerging technologies forms a good basis in understanding the evolution of different kinds of technology roadmaps. Although most respondents in the survey conducted ranked third generation technology roadmaps as the dominant practice of technology roadmapping in South Africa (Table B9, Appendix B), second generation technology roadmaps were ranked the second. Since third generation technology roadmaps involve multiple converging emerging technologies that don't yet have established product platforms (Marinakis & Walsh, 2016; Letaba, Pretorius & Pretorius, 2015; Tierney, Hermina & Walsh, 2013), there is evidence of niche experimentation in South Africa.



As shown in Table B10 (Appendix B), the main priority of innovation programmes that are part of 3rd generation technology roadmaps are market development or entrepreneurship (53.8% of respondents) followed by product development or manufacturing (50.0%) and technological development (50.0%). These represent a typical market pull innovation value-chain. The dominance of emerging multiple technologies oriented roadmaps which are mainly prioritised towards market development or entrepreneurship confirms presence of niche innovation. This comes as no surprise as developing countries are less integrated into the global innovation value-chain (Gereffi & Sturgeon, 2013). The following deduced proposition reinforces the technology roadmap format that is proposed on the theoretical framework:

Proposition 6: third generation technology roadmaps are dominant in developing countries

The literature on third generation technology roadmapping is not well developed yet, although there is a consensus concerning its usefulness for planning of complex root technologies at various technology readiness levels. According to Giasolli et al. (2014), third generation technology roadmaps tackle a problem of progressing a set of technologies rather than settling on one technology as it is the case with second generation technology roadmaps. Furthermore, Kamtsiou (2016) defines a third generation technology roadmap as one that integrates policy, research, industry and organisational roadmapping methodologies in order to manage the development and adoption of systematic innovations in complex domains. Developing countries are an example of such complex environments.

As articulated by Tierney, Hermina & Walsh (2013), each new generation of technology roadmaps has been driven by the changing nature of innovations and products under review. The authors suggested the following distinct manners in which new innovations and products differ from earlier innovations and products:



- They are created at the interface of multiple root technologies.
- Often they do not benefit from a unit cell or root technology as it is the case with the transistor for a semiconductor technology roadmap.
- They are driven by wide applications which will require differing and often multiple critical dimension development for each technology being utilised.
- They are constrained by much stricter boundary conditions.
- The external drivers affecting them are much more important.
- They are driven through new business models such as consortia without the benefit of predetermined architecturally stable product process platforms.

These characteristics of innovations and products that are part of third generation technology roadmaps are intertwined with those of disruptive emerging technologies in which there is no established innovation value-chain. These types of innovations also fit well with the recent concept of the fourth industrial revolution. A focus on third generation technology roadmaps in developing countries is an important step in order to leapfrog developed countries.

6.2.2 Technology roadmapping organisations and target industry

As shown in Table B11 (Appendix B), technology roadmapping activities in South Africa are distributed at various sectoral organisations, although the most notable of these sectors are government (45.0% of respondents), science councils (45.0%), state owned enterprises (37.5%) and large companies (32.5%). Since technology roadmapping activity can be expensive and time-consuming (Zhang et al., 2013), the SMEs might be consultants commissioned by the state owned enterprises to develop these roadmaps on their behalf. Some examples of technology roadmaps developed in South Africa are shown in Table B13 (Appendix B).



Another unit of analysis is technology roadmaps per target industry as shown by Table B12 (Appendix B). The majority of South African technology roadmaps are for innovation planning within the manufacturing sector (52.5% of respondents) followed by electricity, gas and water supply (42.5%), general government (25.0%), agriculture, forestry and fishing (22.5%) and transport, storage and communication (22.5%).

It comes as no surprise that only 2.5% of the respondents mentioned the financial services sector as the target industry for technology roadmaps in which they took part to develop. Since the financial sector uses mainly information and software technology (Lin, Chen & Shao, 2015), most of their technology roadmaps are software technology roadmaps. As explained in the research methodology chapter regarding sampling, software roadmaps were excluded within the scope of this study due to their relative shorter period (Phaal & Muller, 2009).

6.2.3 Time length of technology roadmaps and level of integration

In most instances, South African technology roadmaps span a period of 5-10 years (37.5% of respondents) followed by 10-15 years (30.0%), less than 5 years (15.0%), 15-20 years (10.0%), 20-25 years (5.0%) and more than 25 years (2.5%). As Table B14 (Appendix B) shows, time length of technology roadmaps developed by government, SMEs/ consultants and international organisations is longer (10-15 years) relative to large companies and science councils whose roadmaps span an average period of 5-10 years. A time length of technology roadmaps developed by state owned enterprises, NPOs and industry associations balances between 5-10 and 10-15 years.

Table B15 (Appendix B) shows that in terms of a target industry, the time length of technology roadmaps for the mining industry is relatively longer (between 15-20 years), although an equal proportion of respondents (28.6%) also indicated a roadmapping time length of 10-15 years and 5-10 years. This shows a



balanced portfolio of R&D and innovation programmes within the mining industry.

A shorter time-span of technology roadmaps developed by large companies and science councils seems to take into account existence of short-cycle technologies, especially in relation to the market needs. In fact, roadmaps of a shorter time period, less than five years, are used as a strategy or policy implementation tool (Table B18, Appendix B).

Technology roadmaps developed by large companies and science councils differ in terms of focus as the ones developed by science councils are focused towards R&D agenda setting. Those developed by large companies are focused towards technology platform development. As is the case with other type of organisations, technology roadmaps developed by large companies are well integrated with other internal and external plans (Table B16, Appendix B). The same applies to technology roadmaps per target industry (Table B17, Appendix B), although integration with other internal plans is relatively low for electricity, gas and water supply industry (52.9%).

Building from propositions two and three about the priority of private sector innovation programmes towards technology and market integration, and combining this with the fact that large companies' technology roadmaps are relatively shorter and well integrated with other internal and external plans, the following proposition is deduced:

Proposition 7: private sector technology roadmaps in developing countries are geared more towards technology leapfrogging in relation to the public sector technology roadmaps

The inference about the existence of technological leapfrogging is in line with the necessary conditions suggested by Perkins (2003) about the existence of action from the outset, technology transfer from developed economies,



international assistance, strong incentive regime and a shift towards new sustainable production approaches.

Whereas the public sector and international organisations are championing the role of being the innovation enablers by focusing on R&D agenda setting (El Amine & Abderrezak, 2013), the private sector is focusing its efforts towards technology platform development which would also typically involve learning-by-doing. South Africa has some favourable incentives such as those for the motor industry (Bhorat et al., 2014), R&D tax incentive (Kahn & Hounwanou, 2008) and many more.

6.3 Development of technology roadmaps

The theoretical framework proposed for development of technology roadmaps for developing countries (chapter 3) suggested adoption of transition management and complex systems theory in customising the generic technology roadmapping framework that was proposed by Garcia & Bray (1997). This generic framework has three phases, namely: preliminary activities, technology roadmap development and follow-up activities. In this section, the first two phases are analysed for South African technology roadmaps.

6.3.1 Organisational structures and sponsors for development and implementation of technology roadmaps

Various organisational structures exist for the development of technology roadmaps. The structures of the roadmapping teams can be categorised in terms of centralisation versus decentralisation of roadmapping activities within the organisation, but also in terms of the extent in which the organisation's partners are involved in key roadmapping decisions, including implementation, monitoring and update of roadmaps. Table B19 (Appendix B) shows that the typical structure that is utilised in South Africa to drive technology roadmapping activities is the formation of a new roadmapping team with external partners (67.5% of respondents).



For example, the 2015-2025 South African Water Research, Development and Innovation (RDI) Roadmap was developed by the Water Research Commission (WRC) in partnership with the DST as well as the Department of Water and Sanitation (DWS). United Kingdom based company was contracted to facilitate the technology roadmap development process. An 18 member reference group was set-up from the DST, WRC, DWS, CSIR, Eskom, industry, academia and eThekweni Metropolitan Municipality. This reference group, which was chaired by the board of WRC, met about three times (after every six months) to guide the development of the roadmap.

The involvement of external partners on key decision-making structures in the roadmapping activities is critical. As noted by Garcia & Bray (1997), a technology roadmap should be owned by the group of experts developing the roadmap in order to secure their buy-in and commitment. The authors suggest the inclusion of individuals from the members of the industry, its customers and suppliers, as well as government and universities for the development of industrial technology roadmaps.

For corporate level technology roadmaps, the recommendation is to ensure participation of various structures within the organisation (marketing, planning, R&D, manufacturing, etc.) as well as key customers and strategic suppliers. Table B20 (Appendix B) shows that 30.8% of respondents who participated in technology roadmapping activities for large companies indicated that there was a formation of a new organisation-wide roadmapping team or committee. This organisation-wide technology roadmapping committee is also used for technology roadmaps that are targeted towards usage by government (Table B21, Appendix B).

The type of technology roadmapping sponsor is also related to the type of the organisational structure used for roadmapping activities. As shown by Table B22 (Appendix B), most prominent sponsorship types are organisational internal funding (48.7% of respondents) and government (46.2%). Some examples of



South African government departments that commissioned the development of technology roadmaps are Department of Science and Technology's ICT RDI Roadmap, South African Research Infrastructure Roadmap and Waste RDI Roadmap; Department of Trade and Industry's Electric Vehicle Industry Roadmap and Wind Industry Localisation Roadmap; Department of Energy (DOE)'s SETRM and Department of Health's Roadmap for Nutrition in South Africa.

For transition management oriented technology roadmaps in developing countries, the theoretical framework alluded to the need for balance between technology roadmapping partners who are heavily invested in the current dominant product-technology platform and those that are more flexible in moving towards a new dominant platform. This applies to both sponsors and technology roadmapping structures.

However, in some instances, it is the incumbents that are in a better position to pursue new emerging technologies. SETRM is a good example in which the project steering committee is made-up of current dominant players in the South African energy sector (e.g. Eskom and municipalities as represented by South African Local Government Association). Eskom is a South African state owned enterprise that has a monopoly over the mainly coal-fired electricity industry (Baker, 2011). Many municipalities may be resistant to adoption of renewable energy options such as solar energy due to a fear of losing electricity sales revenue due to decentralised electricity generation (Ntsoane, 2017). This leads to the following research proposition:

Proposition 8: in developing transition-based technology roadmaps for developing countries there should be a balance between involvement of stakeholders from a dominant product-technology platform and those who seek new modes of innovation

This proposition recognises the needs of potential radical innovators within developing countries to access existing social networks, finance and the



innovation value-chain, but also the need to develop new product-technology platforms that might disrupt existing innovation ecosystems. Table B23 (Appendix B) shows that if organisational internal funding is used for technology roadmap development activities, the technology maturity level becomes an important criterion to use for selection of products and technologies that are part of the roadmap (73.7% of respondents). When government or local stakeholders are the roadmapping sponsors, a criterion for selection of products and technologies to be roadmapped is more aligned to market, stakeholders or societal needs.

6.3.2 Tools used for development of technology roadmaps

Most South African technology roadmaps make use of workshops for consensus making processes (80.0% of respondents) followed by expert(s) judgement (65.0%), desktop study (55.0%), vote by key stakeholders (32.5%), forecasting methods (20.0%) and surveys (2.5%). Table B24 (Appendix B) shows that expert(s) judgement as consensus making process is relatively more used on instances in which international organisation(s) is involved as a sponsor (100% of respondents).

Expert judgement and 'educated' gut feel are extensively used by the technology roadmapping community (Amer, Daim & Jetter, 2016; Farrukh, Phaal & Probert, 2003) in place of probabilistic statistics such as forecasting that might not work for long-term planning. Forecasting methods take into context the past in order to inform the future, hence it is not a surprise that this consensus making method is used relatively more in cases where organisational internal funding is used (33.3% of respondents). These methods take into account the forces of organisational inertia and established structural routines in predicting the organisational future. As a result, most technology roadmapping techniques combine both forecasting and intuitive-based methodologies in determining technology futures (Amer, 2013).



Table B25 (Appendix B) shows that other tools that are typically used during technology roadmap development in South Africa are competitive analysis (64.0% of respondents), capability analysis (57.5%), scenario planning (57.5%) and lifecycle analysis (52.5%). All these four techniques are dominant for technology roadmaps that span a period of 10-15 years (Table B26, Appendix B) and for third generation technology roadmaps (Table B27, Appendix B). As summarised by proposition 1, the main priority of innovation in developing countries is technological capability development, hence the use of capability analysis. Scenario planning is ideal for planning of multiple niche innovations that are part of third generation technology roadmaps. This tool is gaining prominence for its application along with the technology roadmapping technique, for example: Lee & Park (2005). According to Strauss & Radnor (2004:51), “a carefully designed and implemented blend of scenario planning and roadmapping can offer the best of both worlds”.

According to Amer (2013), about four or five scenarios should be acceptable as more than five scenarios can take a long time to develop and might be very costly. Although three scenarios are recommended by Pillkahn (2008), the author cautions against this option as there is a risk of focusing on the middle, most likely scenario. Scenario planning is useful for identification of promising product technology platforms and identification of grand challenges as suggested by Walsh (2004).

This leads to the following deduced proposition:

Proposition 9: scenario planning is an appropriate technique to use for selection of technologies and products that are part of technology roadmaps in developing countries

Scenario planning accommodates other dominant techniques identified, such as workshops, expert judgement, competitive analysis, capability planning and lifecycle analysis as they can be used along with this technique.



6.4 Impact of technology roadmaps

The technology roadmapping process doesn't end at the stage in which the final document is signed-off. As it has been a case with the ITRS, there is a need for frequent monitoring and update of the roadmap in order to keep it a live document. However, the biggest challenge encountered by technology roadmapping practitioners is to keep it alive (Vatananan & Gerdsri, 2013). In this section South African technology roadmaps are evaluated in terms of continuation of roadmapping structure and their utilisation. In addition, recommendations are collected from the respondents regarding ways to improve technology roadmaps' development and impact.

6.4.1 Continuation of technology roadmapping structure

One of the ways in making sure that a technology roadmap document is implemented is through assigning a responsibility to a coordinating structure that will ensure that resource commitment is fulfilled and the roadmap targets are updated as and when required. As depicted in Figure 6.1, 39.5% of respondents reported that a technology roadmapping committee or structure is kept alive, whereas 36.8% of respondents said the structure or committee is not kept alive.

For the purpose of this analysis, the indicator of roadmapping structure continuation is used as a proxy for relative maturity of technology roadmapping efforts. Although the difference is not so much if these responses are disaggregated in terms of technology roadmapping organisations (Table 28B, Appendix B), it can be seen that the organisations that are likely to keep alive the technology roadmapping structure or committee are the international organisations in South Africa (42.9% of respondents), NPOs (40%), government (38.9%), international organisations outside of South Africa (37.5%) and SMEs/consultants (37.5%).

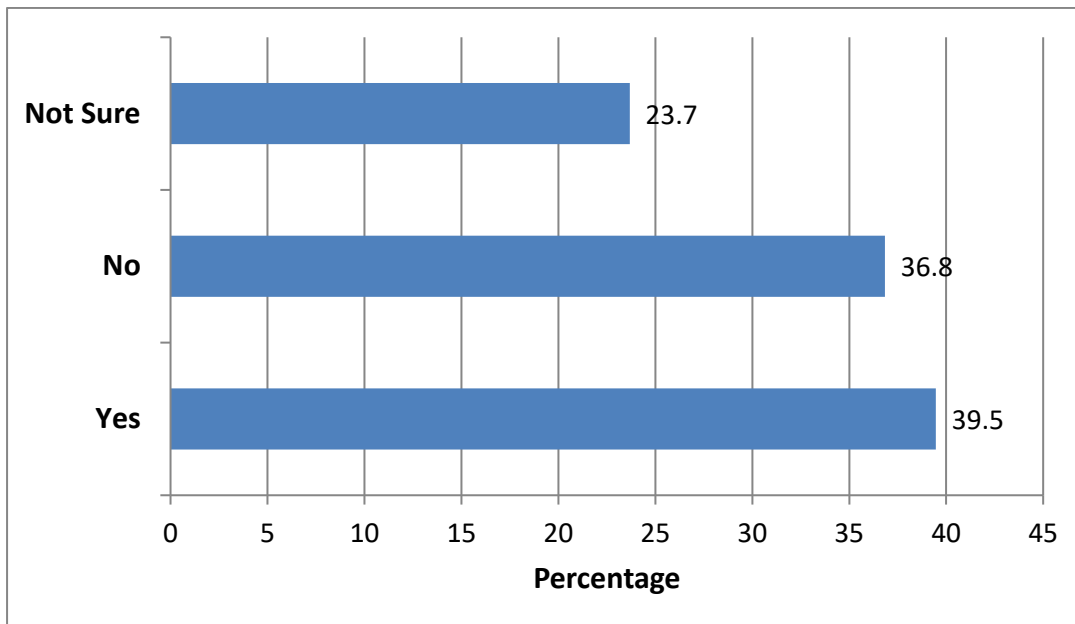


Figure 6.1: existences of technology roadmapping committee/ structure after the initial approval

Table B29 (Appendix B) also confirms the continuation of a technology roadmapping committee or structure largely in cases where international organisations are the sponsors for roadmapping activities (55.6% of respondents). This makes sense, as international organisations such as IEA bring expertise on issues such as global data awareness, competency and reliability of the roadmap. These are some of the critical factors to high-quality roadmaps suggested by Kostoff & Schaller (2001).

A significant percentage of respondents were not sure if the structure/ committee is kept alive or not (23.68%). As Table B28 (Appendix B) shows, the biggest proportion of these uncertain respondents took part on technology roadmaps developed by higher education institutions (50% of respondents) and SMEs/ consultants (37.5%). This comes as no surprise as consultants and academics are not in the core business of ensuring the on-going success of a technology roadmap beyond their development.



6.4.2 Utilisation of technology roadmaps

Several criteria have been proposed in the literature regarding success measures for technology roadmaps (Jeffrey, Sedgwick & Robinson, 2013; McDowall, 2012; Gerdri et al., 2009). A success criterion developed by Gerdri et al. (2009) span across the areas of technology roadmap initiation (acceptance by key stakeholders and development of customised process), development (roadmap content credibility and consensus making process) and integration (linkage between a roadmap and corporate strategic plan as well as continuation of technology roadmap implementation). A criterion for evaluation of transition technology roadmaps development by McDowall (2012) has four dimensions, namely: credibility, desirability, utility and adaptability. The first three dimensions correspond to roadmap evaluation framework of Gerdri et al. (2009) whereas the fourth one is more specific about transition-based technology roadmaps.

As shown in Table B30 (Appendix B), in cases where there is continuation of the technology roadmapping structure or committee, its ongoing functions are mainly implementation of technology roadmap (42.1% of respondents), monitoring of the roadmap (34.2%) and the update of the roadmap (31.6%). Such implementation of technology roadmap actions is typically on a broader scale (Table B31, Appendix B) across organisations, industry or government (55.3% of respondents). The experience of international organisations again comes to the spotlight (Table B32, Appendix B) as this broader implementation mainly takes place for roadmaps developed by international organisations in South Africa (71.4% of respondents) followed by industry associations (66.7%).

As expected, technology roadmaps developed by higher education institutions are once-off exercises and roadmap actions are not implemented. This challenge is also experienced somewhat in cases in which organisational internal funding is used. As Table B33 (Appendix B) shows, roadmap actions are likely to be implemented in cases in which sponsorship for roadmap development was provided by local stakeholders (100% of respondents) and



less broadly of organisational internal funding is used (52.6%). Jeffrey, Sedgwick & Robinson (2013) elaborated in detail about the shortcomings of traditional organisational roadmaps in which the author and intended roadmap audience is a single organisation; and the roadmap purpose typically only acts as a strategic planning tool.

Back to the fourth dimension of Gerdsri et al. (2009) for evaluation of transition technology roadmaps, adaptability entails issues such as whether the roadmap is periodically reviewed, updated and learnings are incorporated. Indeed, this is very useful as transition-based technology roadmaps involve learning by doing through several niche experimentations. Success levels of most of South Africa's technology roadmaps are monitored by technology roadmapping structures or committees (47.4% of respondents) followed by roadmapping sponsors (34.2%). A large proportion of technology roadmaps being monitored by the sponsor indicates the need for such sponsors to develop technology roadmapping capability for themselves.

As explained by Garcia & Bray (1997), technology roadmaps should be owned by a group of experts who developed them as their involvement and commitment is critical. Arms of national government, such as the DST, often falls into the trap of outsourcing the development of their roadmaps to the organisations such as science councils, some examples being the CSIR developed ICT RDI Roadmap and the Waste RDI Roadmap. This is illustrated in Table B34 (Appendix B) in which technology roadmaps developed by NPOs, higher education institutions, international organisations outside of South Africa and science councils are mainly implemented by technology roadmapping sponsors. Table B35 (Appendix B) also confirms this observation in terms of roadmaps sponsored by the government.

Therefore, government departments along with their stakeholders should champion the development of national shared visions through roadmaps whereas science councils and their stakeholders can develop roadmaps that



inform their initiatives to develop R&D and technological capability. South African technology roadmaps are mainly implemented by a roadmapping committee in a situation in which the SMEs or consultants are commissioned for their development (50% of respondents). This leads to the following proposition:

Proposition 10: monitoring and update of technology roadmaps are critically important for transition-based roadmaps in developing countries and such functions should be championed by the owners of the roadmap

This proposition is fundamental in driving the four transition phases articulated in chapter 3, namely: predevelopment, take-off, upscaling and stabilisation. During the predevelopment phase, there are various subsets of niche innovation roadmaps or scenarios that need to be seeded and carefully monitored and evaluated for socio-economic viability. This exercise would assist with the selection of niche innovations that need to take-off and subsequently those that need to be up-scaled. Periodical update of transition technology roadmaps would ensure that the roadmap correctly reflects the changing priorities through various phases.

6.4.3 Measures to improve technology roadmaps development and impact

The ten research propositions deduced are very important for preparation, development and improvement of technology roadmaps. In addition to these analytical propositions, the respondents were asked in general about factors that contribute to success and failure of technology roadmaps. As Table B36 (Appendix B) shows, in terms of factors contributing to the success of technology roadmaps in South Africa, sufficient capacity to implement the roadmap is a dominant factor (51.4% of respondents) followed by executive support (48.7%), external buy-in from stakeholders (48.7%) and relevance of roadmap to key strategic issues (48.7%).

A requirement for sufficient capacity is aligned to proposition 10 in which developing countries' roadmapping owners are encouraged to be actively



involved in the development, monitoring and update of their technology roadmaps. Executive support and buy-in, as also suggested in Table B37 (Appendix B) have been mentioned by several scholars in the literature as vital for success of technology roadmaps (Lee, Phaal & Lee, 2011; Schaller, 2004; Garcia & Bray, 1997). According to Lee, Phaal & Lee (2011), organisations should devote more time and money to roadmaps in order to make sure that they are successful. This can only be achieved if a technology roadmap is well aligned to the strategic goals of the organisation. The need for external buy-in from the stakeholders has also been documented well in technology roadmapping literature (Gerdri, Vatananan & Dansamasatid, 2009) although for transition technology roadmaps in developing countries proposition 8 should be taken into account.

As Table B36 (Appendix B) shows, lack of executive support is mentioned as the main factor contributing to failure of technology roadmaps in South Africa (47.4% of respondents) followed by roadmaps not being kept alive or updated (42.1%). Therefore, even though executive support is required to ensure success of technology roadmaps, it is one thing which is lacking to approximately half of roadmaps developed in South Africa.

This is not surprising if one takes into account the fact that about 18.2% of respondents indicated that roadmaps are a once-off exercise and roadmap actions are not implemented (Table B31, Appendix B). A further 26.3% of respondents reported that technology roadmaps in which they are familiar with are implemented narrowly as they are not integrated across organisation, industry or government. Various scholars have alluded to the importance of keeping roadmaps alive in order to realise the full benefits of a technology roadmap (Gerdri, 2013; Phaal et al., 2003). Similarly, the respondents in this study suggested a strong emphasis on implementation in order to improve the impact of technology roadmaps in developing countries (Table B38, Appendix B).



6.5 Chapter summary

The sixth analytical proposition about the dominance of the third generation technology roadmaps in developing countries is in accord with chapter 5 propositions regarding the main priority of innovation being technological capability development (lack of stable product technology platforms), convergence of emerging technologies from internal and external sources and the timing of the window of opportunity. The window of opportunity relates to the third generation technology roadmaps as in these new form of technology roadmaps the innovation landscape drivers are more important (Tierney, Hermina & Walsh, 2013).

Furthermore, the seventh proposition regarding the private sector technology roadmaps being geared more towards technology leapfrogging is in accord with proposition 2. It was deduced through proposition 2 about the private sector's priority of innovation being technology development and market integration. The remaining three propositions provide some foundation and principles for technology roadmapping in developing countries. Both the scenario planning and a balance between involvement of stakeholders from dominant product-technology platform and those who are transition-oriented, are good guiding principles for development of the third generation technology roadmaps. The last proposition regarding the importance of monitoring and update of transition-based technology roadmaps takes into account the predevelopment, take-off, upscaling and stabilisation phases that are associated with the proposed transition-based technology roadmap (Figure 3.2).

Industrial sectors can experience the transition in different ways, hence in chapter 7 the analytical propositions deduced in chapters 5 and 6 are demonstrated and validated in several key economic sectors (energy, mining and water).



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CHAPTER 7: SOCIOTECHNICAL TRANSITIONS FOR CASE TECHNOLOGY ROADMAPS

7.1 Introduction

The three groups of case technology roadmaps are discussed in this section, namely: energy technology roadmaps, the mining automation technology roadmap and the Water RDI Roadmap. The analytical focus is mainly on sociotechnical transitions taking place within the energy, mining and water sectors in South Africa in the context of the analytical propositions deduced in chapter 5 and 6. The patterns of sociotechnical transitions for these sectors are derived from the qualitative interviews that are coupled with document analysis. The aim of this chapter is to provide more meaning to a derived technology roadmapping framework for developing countries.

Sociotechnical transitions for energy technology roadmaps in developing countries present a very unique and interesting case due to the dynamic nature of the energy industry, but also the potential competition between the niche innovators and incumbents. Mining industry sector value added as percentage of GDP is on the decline in South Africa, hence the industry is in need to adapt for more productivity and efficiency gains. Due to recent evidence of changing climate patterns in South Africa, such as droughts and floods, the water industry is under much strain and patterns of water supply and usage need to be adapted for sustainability of the sector.

7.2 Energy technology roadmaps

As previously stated on section 5.3.2, most of the technology roadmaps in South Africa are in the energy sector. This sector is also important due to its multiple emerging technologies such as wind, concentrated solar power (CSP) and photovoltaic (PV) technologies, energy storage technologies, waste energy, electric vehicles, etc. Some of these energy technologies have already proven



themselves in increasing the electricity generation capacity while reducing the amount of carbon dioxide (CO₂) emissions (Cochran, 2015).

The roadmaps investigated as part of this section include the Solar Energy Technology Roadmap, South African Electric Vehicle Industry Road Map, the South African Solar Thermal Technology Road Map (SA-STTRM), Carbon Capture and Storage (CCS) Roadmap and the Wind Energy Industry Localisation Roadmap. This section discusses and analyses the South African energy technology roadmaps and relevant strategies. Sociotechnical transitions are considered holistically, incorporating all the case energy technology roadmaps.

7.2.1 The Integrated resource plan for South Africa

The 1998 White Paper on Energy Policy introduced the need for an energy IRP in South Africa as a decision-making process concerned with the acquisition of least-cost energy resources, which takes into account the need to maintain adequate, reliable, safe, and environmentally sound energy services for all customers (DOE, 1998). This would have to be achieved through:

- The evaluation of all candidate energy supply and demand resources in an unbiased manner;
- The systematic consideration of a full range of economic, environmental, social, and technological factors;
- The consideration of risks and uncertainties posed by different resource portfolios and external factors, such as fluctuations in fuel prices and economic conditions; and
- The facilitation of public consultation in the utility planning process.

This policy encourages the entry of multiple players in the energy generation market (co-generated and independently generated) and during the development of this policy it was estimated that as much as 6 000 MW of non-



utility generation (mainly from renewable and environmentally sound electricity generation technologies) could be exploited.

As shown in Table 7.1, the 2010 – 2030 IRP seeks to transition the national energy mix from heavy reliance on fossil coal energy (90% in 2010) to the environmentally friendly low carbon energy mix (65% contribution from fossil energy). This plan discusses in detail the uncertainty between nuclear and renewable energy; and it allows room for policy learning through subsequent revisions of the plan.

Table 7.1: current and IRP planned electricity mix on the national grid

	Coal	Nuclear	Hydro	Gas	Renewables
2010	90%	5%	5%	<0.1%	0%
2030	65%	20%	5%	1%	9%

The 2016 IRP update (DOE, 2016) discusses in detail various scenarios and it has a decision tree for each technology option. The National Development Plan (NDP) recommends the following key initiatives in the energy sector in order to improve the country's energy situation: i) balancing of growth in coal exports against the need for domestic coal-supply security, ii) exploration of gas as an alternative to coal for energy production, iii) the need for a greater mix of energy sources and a greater diversity of independent power producers (IPPs) in the energy industry, iv) improvement of municipal electricity-distribution services, v) accommodating of the needs of the poor in electricity pricing and access and vi) a careful consideration of the timing and/or desirability of nuclear power and a new petrol refinery.

7.2.2 Solar energy technology roadmap

The initial SETRM was commissioned by DST to the CSIR in order to enable an emerging solar energy industry, which can address the challenge, and also contribute to energy resources diversification in the country. As this initial roadmap focussed mainly on R&D and technologies, a process to revisit the roadmap was initiated in 2012 by DST and DOE with the support of the CSIR



and the South African National Energy Development Institute (SANEDI). The integrated roadmap incorporates the energy policy and strategies; as well as local energy security needs. According to Brent (2015), the SETRM focuses on the generic active solar technology platforms pertaining to both power and thermal energy services; and specifically PV and CSP systems.

The solar industry has grown drastically in recent years from a small-scale industry in Germany to a more than \$100 billion solar-PV business globally; and this growth is driven by government subsidies, significant capacity additions for existing and new entrants, and continued innovation (Aanesen, Heck & Pinner, 2012). However, according to Beaudin et al. (2010), the variability of the renewable sources of electricity such as solar energy poses technical and economic challenges when integrated on a large scale. Solar energy is variable during the day and the peak irradiance occurs mostly during a midday (Hoff & Perez, 2010).

Various energy storage solutions have been investigated in order to reduce this variability by time-shifting of renewable energy supply. Agbossou et al. (2004) demonstrated a standalone wind turbine generator (WTG) and PV renewable energy system with hydrogen as an energy storage solution.

7.2.3 The South African carbon capture and storage roadmap

This five phase roadmap (Figure 7.3) was developed by the DOE in collaboration with SANEDI and the South African Centre for Carbon Capture and Storage (SACCCS) in acknowledging the importance of fossil fuel and its dominance as primary energy (electricity and petroleum production). Although there is a worldwide energy transition from coal usage, due to high CO₂ emissions, to renewable energy, coal remains an abundant resource in countries such as South Africa. According to the Chamber of Mines of South Africa (n.d.), the country ranks 6th in the list of coal exporting nations (6% share of global exports), has 3.5% of the world's coal resources and produces 3.3% of the world's annual total.

The CCS roadmap aims to develop a portfolio of technologies to reduce CO₂ emissions and to meet climate change goals. This roadmap is currently in the third phase (Pilot Storage) and the plan is to capture and store carbon at the scale of 10,000 tonnes (Figure 1). At the demonstration phase, the CCS capacity should be ten-fold and million tonnes of carbon should be captured, transported and stored at the commercial phase by 2025.

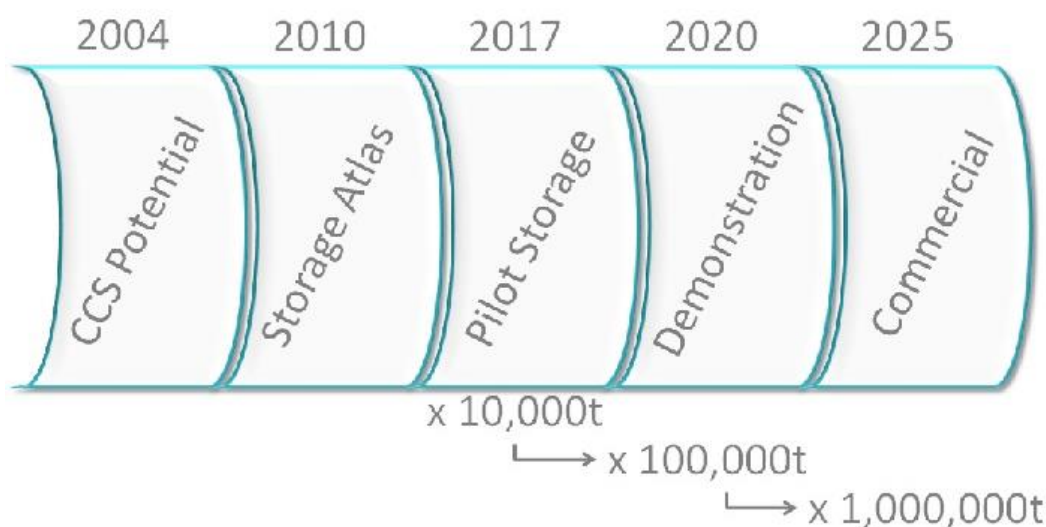


Figure 7.1: South African carbon capture and storage roadmap

Source: SACCCS (n.d.)

Some of the technologies/ programmes that are part of the CCS roadmap are determinations of the CO₂ Geological Storage Atlas, technologies for safe injection of CO₂ into reservoirs, assessment of local geology as a suitable storage medium, impact assessment of CO₂ storage on the surrounding storage medium, etc. These activities are strategically aimed at demonstrating the sustainability of CCS and to maintain fossil fuels as a valuable component of the energy mix.

As shown in Figure 7.2, geological storage of CO₂ involves its injection into appropriate geologic formations that are typically located between one and three kilometres under the ground; and subsequent monitoring of injected CO₂ (International Energy Agency, 2013). Furthermore, suitable geologic formations include saline aquifers, depleted oil and gas fields, oil fields with the potential for



CO₂-flood enhanced oil recovery, and coal seams that cannot be mined with potential for enhanced coal-bed methane recovery.

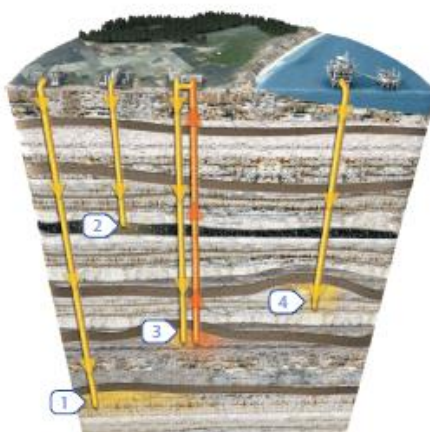


Figure 7.2: underground carbon storage options

Source: International Energy Agency (2013)

Several countries have introduced regulatory frameworks for CO₂ storage in order to manage environmental and health risks. In South Africa, the related legislations that guide CCS activities are the National Environmental Management: Waste Act 59 of 2008, Mineral and Petroleum Resources Development Act No. 28 of 2002 and laws relating to occupational health and safety and transportation of dangerous and/or hazardous substances (ERM, 2013).

7.2.4 South African nuclear energy policy

The 2008 South African Nuclear Energy Policy has a vision of industrial and technological leadership to secure alternative energy resources for the future, through the development of a globally competitive infrastructure and skills in the peaceful utilisation of nuclear energy and technology. Although nuclear energy only contributes to less than 5% of energy produced within the national grid, South Africa decided in 2004 to develop and market the country's pebble bed modular reactor (PBMR) technology through the production of 4,000 to 5,000 MWe of power using about 25 to 30 PBMR modules (Hevia & Slabber, 2005).



This project was abandoned in 2010 mainly due to technical complexities for commercialisation of the High Temperature Gas-cooled Reactor design and project budget overruns (Thomas, 2011). Nuclear energy is an attractive option for the policymakers in South Africa due to the abundance of uranium, an important raw material for the nuclear reactors. Some objectives of Nuclear Energy Policy related to uranium are specifically:

- To exercise control over un-processed uranium ore for export purposes for the benefit of the South African economy; and
- To allow for the participation of public entities in the uranium value-chain.

Since the abandonment of a PBMR initiative, there has been a drift towards a matured imported nuclear energy technology. This energy option has attracted much public debate regarding nuclear procurement. Analytical work by Rennkamp & Bhuyan (2016) combined the discourse network analysis with qualitative analysis to establish the coalitions in support and opposition of the nuclear programme.

Those in support of this programme base their stance on factors such as energy security, baseload generation, economic growth, local skills development, job creation, emissions reduction, cost effectiveness, safety, industrial development, ease of maintenance and local uranium resources. The coalition of opponents of this programme complains mainly about the potential astronomical cost of nuclear power stations, long-term success prospects for the renewable energy programme, safety concerns in relation to recent nuclear plants' disasters, lead times to build nuclear power plants, slow economic growth, transparency in nuclear procurement, potential corruption, out-dated technology, environmental degradation, etc.

7.2.5 National hydrogen and fuel cell RDI strategy

The vision of this 15-year Hydrogen South Africa (HySA) strategy (launched in 2008) is to use local resources and existing knowledge to create knowledge and



human resource capacity, enabling the development of high-value commercial activities in hydrogen fuel cell technologies (HFCTs). This 2007 strategy is uniquely discussed as part of technology roadmaps for energy sociotechnical transitions due to the important role that HFCTs can play in energy storage. Hydrogen is an important energy carrier as it can be produced from nuclear, coal, solar or biomass. The specific programmes planned from this strategy are:

- Establishment of a base for hydrogen production, storage technologies and processes;
- Establishment of a base for developing catalysts based on platinum group metals (PGM) resources; and
- Building on the existing global knowledge and HFCT to develop niche applications to address regional developmental challenges.

The HySA strategy is implemented through the three DST Centres of Excellence (CoEs), namely: HySA Infrastructure, HySA Catalyst and HySA Systems. The HySA Infrastructure CoE is co-hosted by the North-West University and CSIR; and it is responsible for RDI programmes for hydrogen production, storage and delivery. The HySA Catalyst, co-hosted by the University of Cape Town and Mintek, is responsible for RDI programmes on components in the early part of the value-chain, catalysts and catalytic devices. Lastly, the HySA Systems which is hosted by the University of Western Cape has the following objectives:

- Development of hydrogen fuel cell systems and prototypes; and
- To perform technology validation and system integration in the three key HySA programmes:
 - Combined heat and power (CHP);
 - Portable systems; and
 - Hydrogen fuelled vehicles (HFVs).

There is a growing international interest in HFCTs based on the increasing concern about energy security, a cleaner environment and, in the long-term,

sustainable energy development. As shown in Figure 7.3, hydrogen can connect different energy sectors and energy transmission and distribution networks, and thus increase the operational flexibility of future low-carbon energy systems (International Energy Agency, 2015).

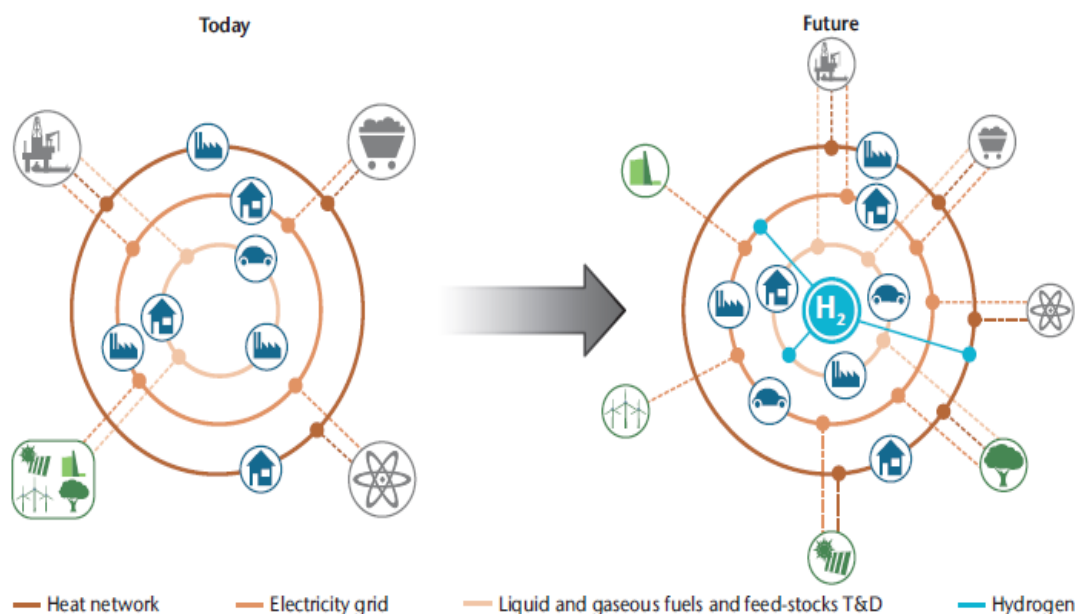


Figure 7.3: hydrogen-buffered energy system of the future

Source: International Energy Agency (2015)

7.2.6 Sociotechnical transition of the energy system

The energy transition complex technology roadmap is shown in Figure 7.4. This transition-based technology roadmap proposed by Letaba, Pretorius & Pretorius (2015) has three levels on the vertical axis, namely: energy innovation landscape, dominant energy innovation regime and niche energy innovations. The multi-level analysis of sociotechnical transition of energy systems is a widely studied topic in technology management literature. For example, Geels (2011) investigated the impact of the financial-economic crises on regimes in concrete empirical domains (food, mobility and energy) which can affect investor confidence, availability of capital, public concerns and the political will to act in favour of sustainability.

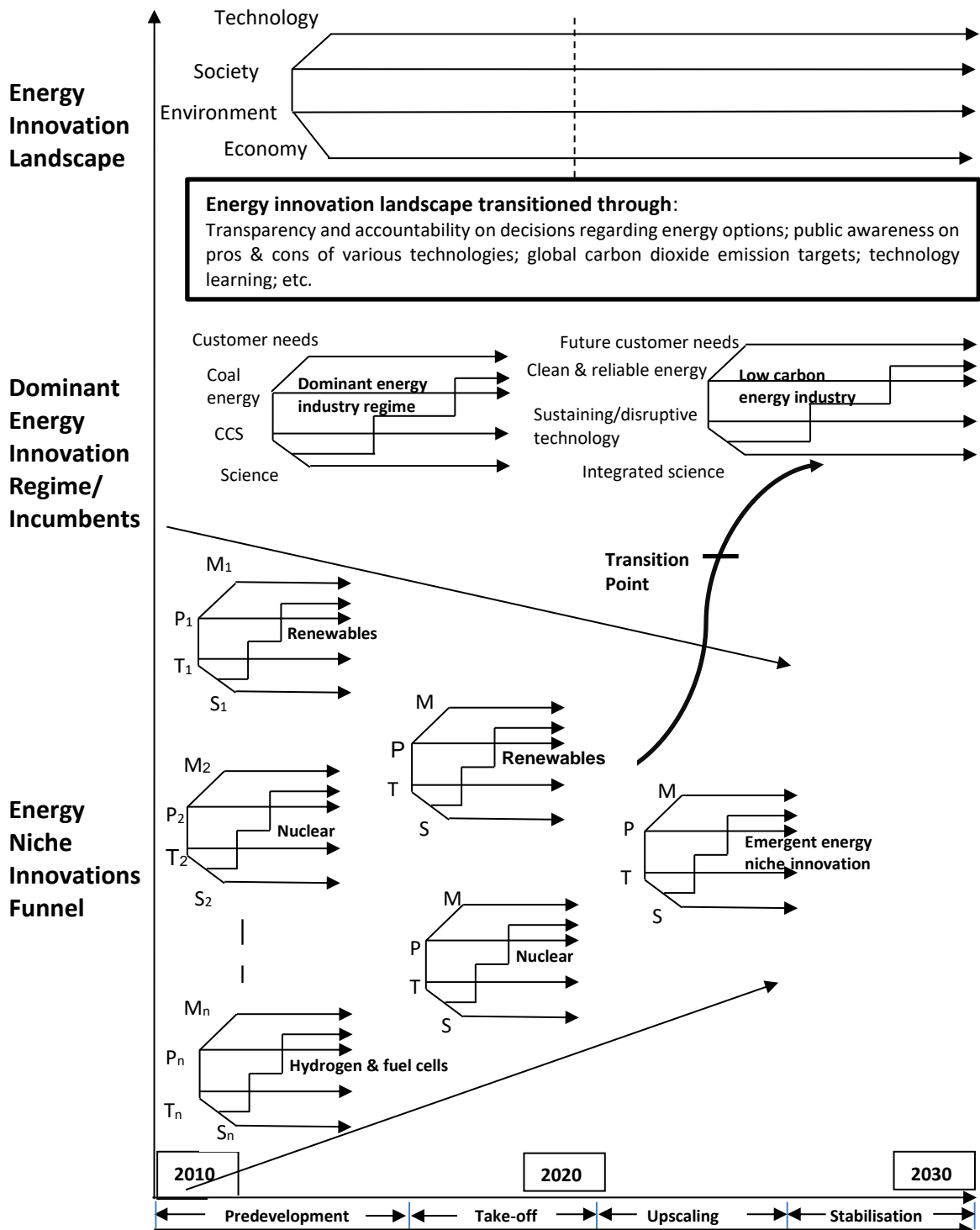


Figure 7.4: South African energy planning sociotechnical transitions



Energy innovation landscape:

The dominant macro factors identified for energy transition in South Africa are technology, environment, economy and society. Various energy niche innovations are at various technology maturity levels, which influences the energy investment decisions, PBMR being a good example. Technology learning introduces a shake-up to both the dominant innovation regime and niche innovation. The 2016 IRP update takes into account this phenomenon and it uses the scenario-based planning with the possible energy investment decision triggers such as the rate of economic growth. The technology maturity level has a direct impact on energy security of the country (ability to provide a stable base load power); hence it is an important component of the energy innovation landscape.

Environmental performance and targets in terms of CO₂ emissions also influence the energy innovation landscape. South Africa is ranked 13th in the world in terms of CO₂ emissions per capita (Statistica, n.d.). According to Wu et al. (2014), the economic growth has an increasing effect on South Africa's CO₂ emissions and these emissions are directly proportional to the increase in urban population and energy consumption. The economic climate also influences technology options as is the case with the negative public discourse in South Africa with regard to nuclear energy technology.

On the issue of negative and positive public discourse, in democratic countries such as South Africa, societal views can drastically influence the energy investment decisions. Public discourse has different phases (gap phase, political phase, legislative phase and litigation/ coping phase) as summarised in Figure 7.5.

There is a wide consensus that energy investment public discourse in South Africa is at the political phase, which is characterised by large media, public and legislative interest.

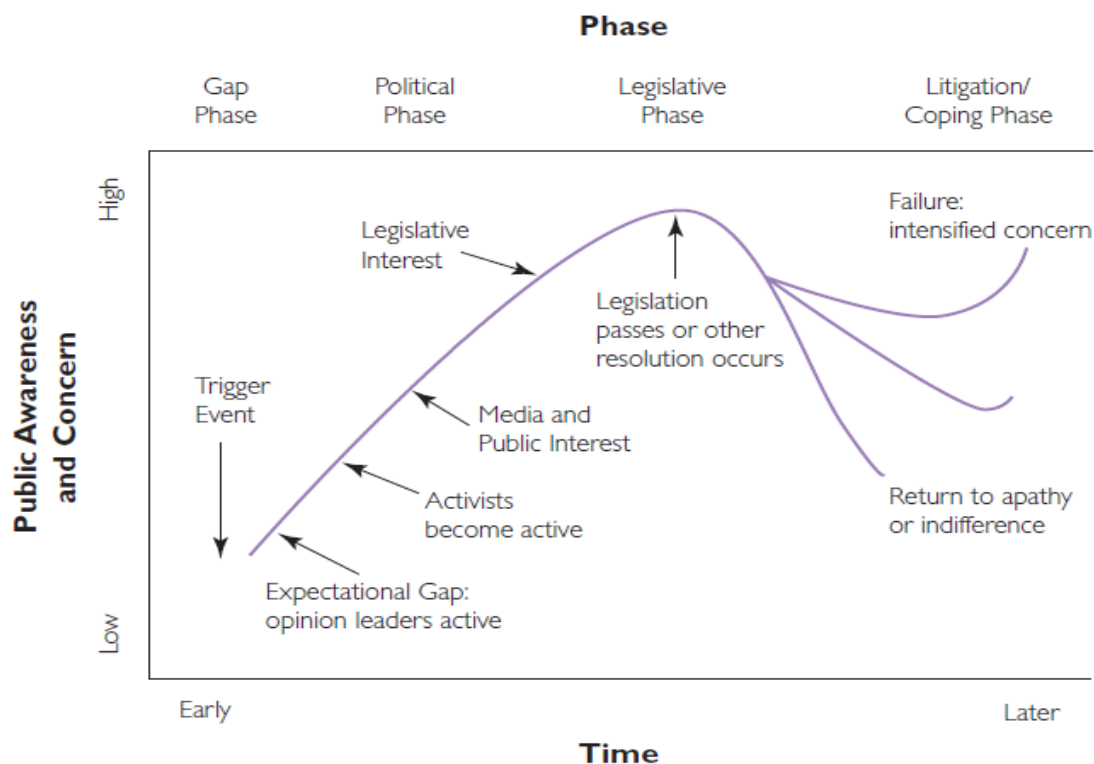


Figure 7.5: evolution of public discourse on national issues

Source: Rivoli & Waddock (2011)

Dominant energy innovation regime and niche innovations:

The dominant energy innovation regime in South Africa is based on coal powered energy production. The main threat for these incumbents is alternative renewable energy sources that have the potential to reduce CO₂ emissions. As a response to the market expectation of clean and reliable energy, the industry is investigating new technologies such as CCS. Should CCS technology prove to be successful, the fossil-fuel based economy will prevail for many more years to come.

The energy niche innovations in South Africa include renewables (wind, solar, etc.), nuclear energy technology as well as hydrogen and fuel cells. The latter is not well factored into the country’s energy plan and the main reason given is the fact that hydrogen production is still very expensive and in most cases hydrogen is produced from fossil sources. These factors might change as the innovation



landscape changes, as the wider adoption of hydrogen as an energy storage solution will imply that there is a reduction in costs due to economies of scale. The take-off phase therefore only incorporates renewable and the nuclear energy.

The country is not yet at the upscaling phase due to the shocks resulting from the opposing public discourses. The emerging energy niche innovation will likely be a mixture of various niche innovations (including hydropower) at various scales. The anticipated low carbon energy industry by 2030 will either be dominated by CSS or energy storage sustaining technologies or by disruptive renewable energy technologies, depending on how the energy innovation landscape unfolds with time. As pointed out before, fuel cell technologies can serve as an energy storage solution for different technology options (including fossil energy), hence they can be either sustaining or disruptive.

7.3 Mining automation technology roadmap

Various industries are undergoing drastic changes in line with the fourth industrial evolution, which is driven by the development and diffusion of cyber-physical systems. Mining is not an exception as various leading global firms in this industry are advancing their technological capabilities in order to achieve zero-harm, efficient and a profitable mining business. This section analyses a case of mining automation roadmap in terms of its nature, its development and sociotechnical transitions that are taking place for transition from manual to automated mining.

7.3.1 Mining automation technology roadmap development process

The objective of the Anglo Platinum Roadmap to Automation is to improve efficiency and safety in the South African platinum sector, which will include the reviewing of mine planning, design and layout. This roadmap was allocated a sponsor, a senior executive within the company, and the vendors were invited to participate in the roadmapping process. It was important to ensure that the objectives of these vendors are aligned to those of the company, although some



of them diverged from roadmap objectives over time as they pursued something different (e.g. new markets). As the roadmap is implemented, some decisions had to be taken on whether to accelerate or decelerate certain technologies.

This roadmap aligns with the parent Anglo American's overall strategy to focus on modernising mining operations by incorporating new mining technologies which results in improved safety and injury-free production, cost-efficiency, increased profitability and a reduced energy footprint. Mining automation has gained prominence around the world as part of the race towards the fourth industrial revolution as companies try to maximise the operational efficiency opportunities brought by information and communication technologies. Technology roadmaps therefore are important for this industry to adapt to new mining methods.

As the results of quantitative survey shows (Table B17, Appendix B), in general, the South African mining industry's technology roadmaps are integrated with other internal roadmaps (85.7% of respondents) and also with other external plans (85.7%). Most of the respondents also indicated that mining industry technology roadmaps are developed through a formation of a new roadmapping team with the external partners. This integrated development of mining industry technology roadmaps is important as mining technology is often developed by original equipment manufacturers outside of the company. Within this multi-stakeholder technology roadmapping process, expert judgement and workshops are typically used for consensus making process (85.7% of respondents) followed by a desktop study (57.1%) as shown by quantitative survey data, for technology roadmaps that are targeted towards the mining industry.

Forecasting methods, surveys and vote by key stakeholders are tools which are seldom used for consensus making process. Since these technology roadmaps incorporate emerging technologies such as nanotechnology, big data, robotics/automation and photonics (Figure 7.6), forecasting methods would not be useful as it relies on past data. In case of emerging technologies, there is a shortage



of past data that can be used for the forecast (Rohrbeck & Gemünden, 2008) and the same applies to surveys which are unsuitable on new topics.

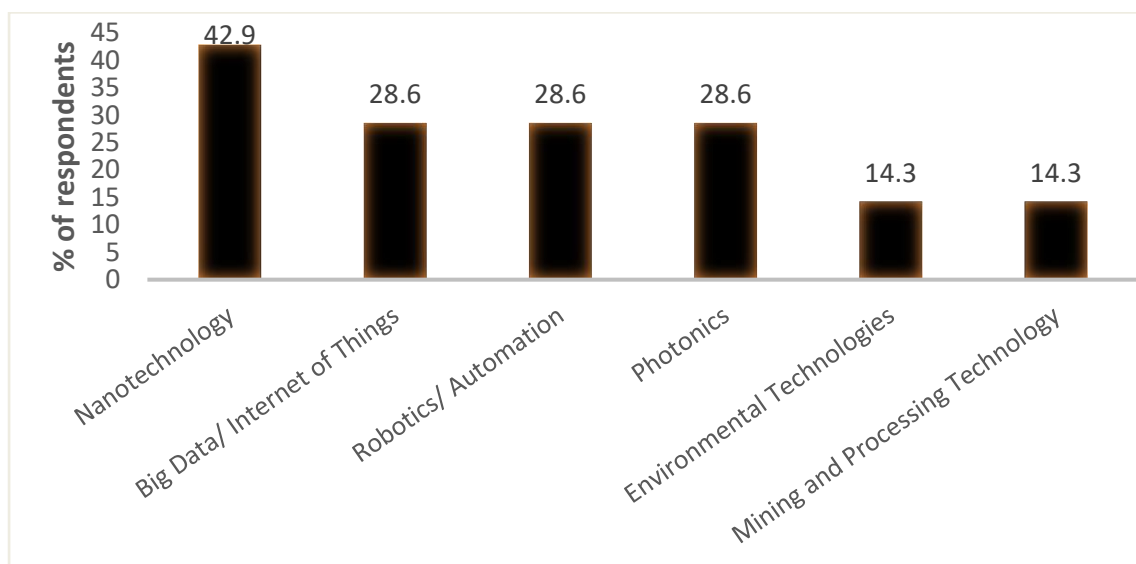


Figure 7.6: emerging technologies included in mining industry technology roadmaps

As derived from the quantitative survey data, other dominant tools that are used for the development of mining industry technology roadmaps are scenario planning (71.4% of respondents), competitiveness analysis (57.1%) and lifecycle analysis (42.9%).

7.3.2 Mining automation technology roadmap sociotechnical transitions

The generic sociotechnical transition mining industry technology roadmap (Figure 7.7) has a time period of 20 years as an equal proportion of respondents (28.6% each) who participated in developing mining technology roadmaps indicated time periods of 10, 15 or 20 years (Table B15, Appendix B).

Mining Innovation Landscape:

At the macro level, the main factors influencing the mining innovation landscape were found to be technological developments, labour policy, the nature and availability of mineral deposits as well as the economic climate (Figure 7.7).

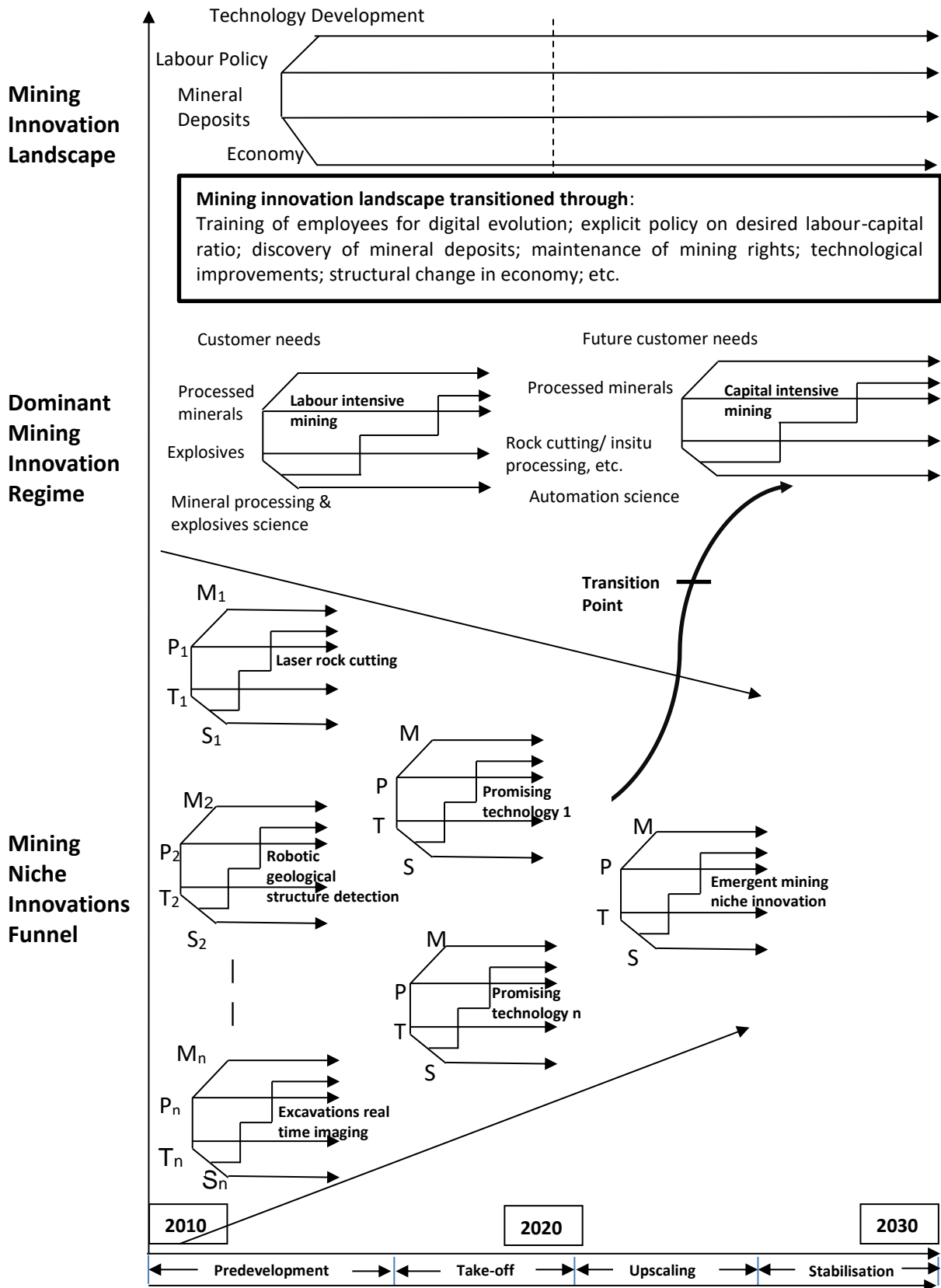


Figure 7.7: mining automation sociotechnical transitions



Most of the technology used for mining is supplied by the original equipment manufacturers and a pace of mining technology development can affect the success of a mining company in achieving its objectives. This was echoed by a senior executive at a global South African mining company who iterated that as part of their mining automation technology roadmapping process they invited the vendors to take part. Some of the vendors diverged from the roadmap objectives as time progresses in pursuit of something different.

The labour policy is also dominant for the mining innovation landscape, especially in relation to the recent industrial actions within the South African platinum mining companies. There is no policy certainty in South Africa around the desirability of mining automation and there are fears that automation can replace jobs, especially the unskilled labourers who would find it difficult to be reskilled to new jobs in a digital world. According to Wilson et al. (2013), policy certainty is important in order to attract the mining investments needed for long-term and sustained industry success.

The productivity growth sub-model by Tasrif (1995) attempts to show the interface of technology and jobs, using the productivity function as a performance measure, but also incorporating other developing countries' constraints such as aggregate demand, international trade, debt levels and the explicit capital to labour ratio policy. This type of a model can be beneficial if it is used for evidence-based policy to guide the mining innovation landscape in South Africa.

In this study of Tasrif (1995), three simulations are run as follows:

- i) Fixed scenario: productivity growth behaviour in response to fixed capital to labour ratio assumption;
- ii) Market scenario: capital to labour ratio is allowed to change adaptively and the recognised capital to labour ratio is used to determine the capital to labour ratio operating goal; and



- iii) Targeted scenario: the operational capital to labour ratio is set externally and it is increasing gradually.

In the targeted scenario, the capital to labour ratio is the highest and the unemployment rate rose initially, although in the medium to long term it declined as aggregate demand increases. This scenario is also accompanied by an increase in productivity, real wage rate and high debt levels. The policymakers therefore need to be actively involved as part of the digital evolution in order to create policy certainty for industries and to attract the much needed capital investment.

The nature and type of the reef for mineral deposits also determine the success or failure of mining automation as it was the case with Lonmin Platinum mine (Nong, 2011). In a less concentrated and complex mineral deposit such as platinum, the ore grade dilution can hamper the effort towards mining automation. The vendor technology is once more important in this case to respond to such challenges. Mining automation requires a huge capital investment hence the economic climate can influence the innovation landscape.

Dominant Mining Innovation Regime:

The dominant mining industry innovation practice (Figure 7.7) is based on drilling and blasting through explosives. Emerging technologies can be disruptive or enabling to certain industries (Letaba, Pretorius & Pretorius, 2014) and the same applies to mining automation technologies. Robotic manipulators, computer vision and other automation technologies can be used to enhance rock blasting techniques, although in other instances a totally new set of technologies need to be deployed to achieve automation, an example being laser rock cutting.

Mining Niche Innovations:

In addition to emerging mining automation technologies such as laser rock cutting (Figure 7.7), there is a global rush to build and deploy technologies such



as autonomous load, haul and dump (LHD) trucks, robotised geological structure detection, excavations real time imaging, autonomous blast and drilling systems, ‘*in situ*’ mineral processing, etc. As a senior mining executive elaborated as part of the qualitative interviews, “as the roadmap is implemented, some decisions had to be taken on whether to accelerate or decelerate certain technologies”. The promising technologies in the near future would make it through the transition point in achieving the automated capital intensive mining industry. However, the transition point can be very stormy as a significant investment is required to upscale the niche innovations and trade wars can result in case of disrupting technologies (Navarro, 2003).

7.4 Water research, development and innovation technology roadmap

The South Africa’s Water RDI Roadmap is a ten year high-level plan (2015-2025) that facilitates and guides refocusing of research, reprioritisation of funds, synergising of existing initiatives and ring-fencing of new resources in order to facilitate a more effective water innovation system (Water Research Commission, 2015). The key objectives of this roadmap are to:

- Increase the availability of water;
- Improve the governance, planning and management of supply and delivery of water;
- Enable water and sanitation services to operate as a sustainable ‘business’; and
- Increase the efficiency and productivity of water usage.

7.4.1 Water RDI roadmap development process

This national roadmap was developed by the WRC in partnership with the DST as well as the DWS. United Kingdom based company, was contracted to facilitate the technology roadmap development process. An 18 member reference group was set-up from the DST, WRC, DWS, CSIR, Eskom, industry, academia and eThekweni Metropolitan Municipality. This reference group, which



was chaired by the board of WRC, met about three times (after every six months) to guide the development of the roadmap.

As shown in Figure 7.8, the technology roadmap development framework for this roadmap followed a standard roadmapping approach of defining the context (know-why), programmes, services or products (know-what), technologies or processes (know-how) and resources (investment required, etc.). This 11-step process involved the stakeholders from 62 organisations and a total of 32 work sessions and workshops.

Although the standard technology roadmapping framework was utilised, the content of the technology roadmap layers differs from market, products, technology and R&D format. For example, the customer needs should ideally be defined as part of the context. The seven clusters that resulted from customer needs identification (from four sectors: agriculture, industry, public sector and environment) and subsequent clustering and narrowing down (Delphi technique) are as follows:

Water Supply:

- Cluster 1: increase ability to make use of more sources of water, including alternatives;
- Cluster 2: improve governance, planning and management of water supply and delivery;
- Cluster 3: improve the adequacy and performance of water supply infrastructure; and
- Cluster 4: run water as a financially sustainable 'business' by improving operational performance.

Water Demand:

- Cluster 5: improve governance, planning and management of water demand and use;



- Cluster 6: reduce losses and increase efficiency of productive use of water; and
- Cluster 7: improve performance of water pricing, monitoring, billing, metering and collection.



Figure 7.8: sequential steps for water RDD roadmap development process

Source: Water Research Commission (2015)

The research, development and deployment (RDD) responses were formulated based on two criteria, namely: attractiveness (customer needs; market opportunity and the value and impact) and fitness (know-how, capability, infrastructure and partnerships). These RDDs were identified for each cluster across the innovation chain (explore, test, demonstrate and deploy) and they include the responses such as:

- The focus and evolution of RDD activity;



- Knowledge generation and exploitation;
- Building of research capacity;
- Implementation of the research infrastructure required; and
- Identification of key customers and suitable partners.

The Water RDI Roadmap's RDD responses are driven through different programmes such as the Water Technologies Demonstration Programme (WADER). This programme was recently established by DST in collaboration with the WRC to pull together the applied R&D and commercialisation stages of the water innovation continuum (WADER, n.d.). The technology facilitator functions of WADER include building a pipeline of water technology demonstrators; promotion of early adoption of innovative water technologies; central coordination of funds and other resources for technology demonstrators; establishment and maintenance of relevant tools and guidelines for technology demonstrations and assessment; and promotion of water entrepreneurship and skills development in the water technology space.

7.4.2 Water RDI roadmap sociotechnical transitions

Figure 7.9 shows the transition-based Water RDI Roadmap. In line with the complex systems framework, the roadmap has three levels, namely: water innovation landscape, domination innovation regime and RDD responses (niche innovations) on the seven prioritised clusters.

Water sociotechnical transition is a widely studied topic with the focus on areas such as interaction between social and ecological systems; interaction between key actors who decide the path and outcome of the water management process; and analysis of urban water governance regimes and transition processes towards adaptive water management (Acheampong, Swilling & Urama, 2016).

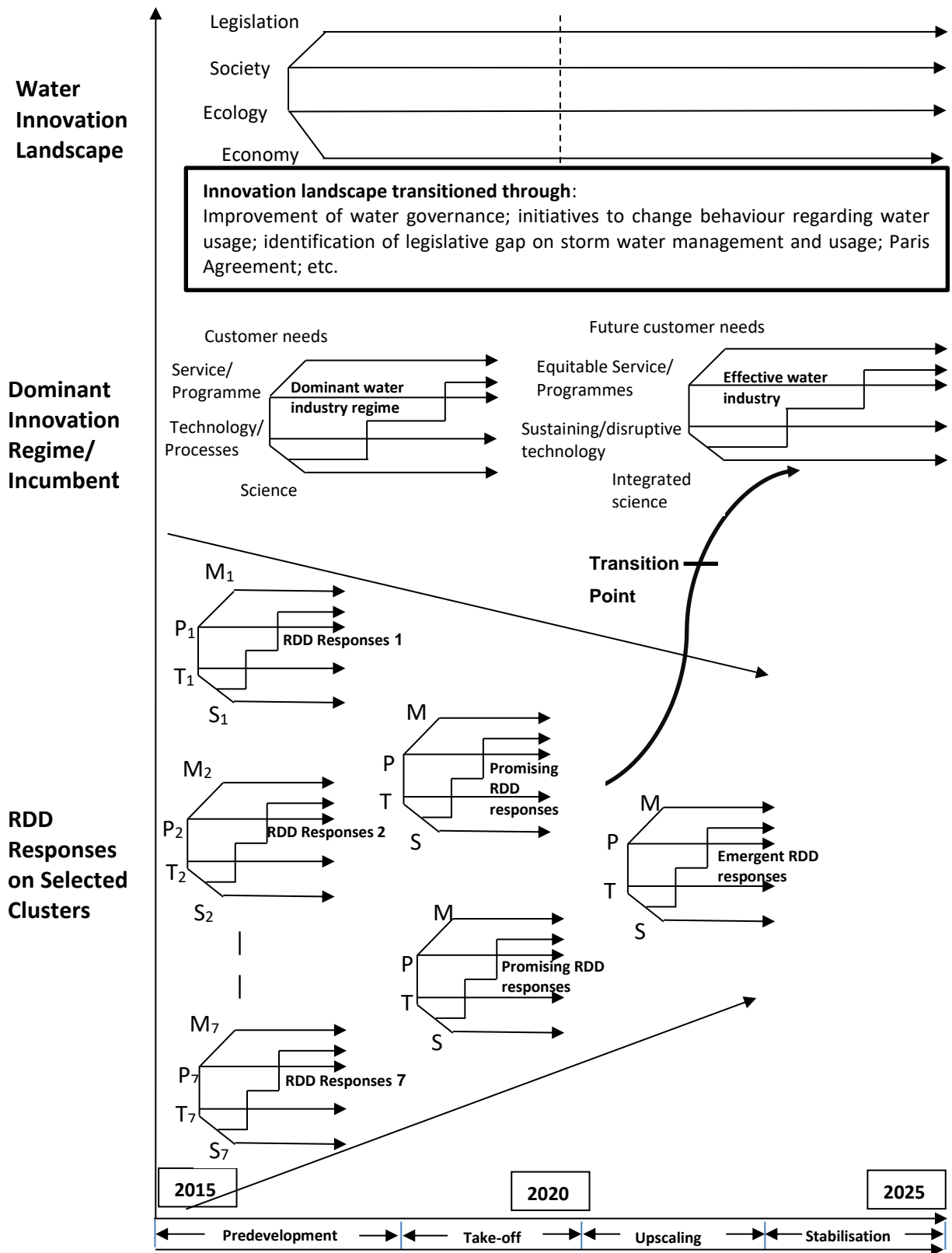


Figure 7.9: Water RDI roadmap sociotechnical transitions



Water innovation landscape:

The South African Water RDI Roadmap takes-off around the innovation landscape characterised by a slow economic growth climate, water scarcity due to drought and an increasing global warming. The transitions at this level take place through various mechanisms such as improvement of water usage and supply governance; and the initiatives to change the societal and institutional behaviours on water usage (Figure 7.9).

According to the World Water Council, the Paris Agreement (CoP21) is directly related to water as climate change manifests itself most powerfully within the water cycle. Water governance in South Africa is guided by the National Water Policy White Paper of 1997, the Water Services Act of 1997 and the National Water Act of 1998. These policy documents advocate for reversal of unequal supply and usage of water (which resulted from 'apartheid' policy), promotion of efficiency in supply and usage of water and growth in sources and supply of water. The decentralised water governance in South Africa is achieved through the Catchment Management Agencies who carry out the functions such as water resources planning in the water catchment area, registration, water charge collection, water authorisation, and licensing (van Koppen, Jha & Merrey, 2005).

Dominant water innovation regime and niche innovations:

The niche innovations (RDD responses) within the Water RDI Roadmap support and promote efficiency on the current dominant regime/ incumbents (Figure 7.9). Cluster 5 identifies the type of incumbents in terms of water demand and usage in terms of those who are interested in economic growth and development (bulk water users in manufacturing, agro-processing, etc.) and those who are interested in the need for water and food security. The roadmap seeks to achieve the balance between these two types of incumbents, although it doesn't set any transition targets in achieving this balance.



According to Department of Water Affairs (2013), 60% of water in South Africa is used for agriculture/ irrigation followed by municipal/ domestic usage (27% total: 24% urban and 3% rural), power generation (4.3%), mining (3.3%), industrial (3.0%) as well as livestock watering and nature conservation (2.5%). These stakeholders were well represented on roadmapping workshops. In the context of water, food and energy nexus, the Water RDI Roadmap is not explicit about energy and food security plans, although they can be a serious competition for water in a catchment area.

In terms of water supply, the key sociotechnical transition is with regard to the mix of water sources. The roadmap seeks to promote development of technologies, capacity, information and management methods to increase the use of treated effluent, decrease levels of salinity through desalination, increase rainwater harvesting and the use of groundwater. According to the National Water Resource Strategy (Department of Water Affairs, 2013), water management is complex resulting from the interaction of social, economic and ecological environment.

The Water RDI Roadmap hence needs clear targets and outcomes, effective monitoring and evaluation as well as frequent updating to reflect the changing environment. Part of the technology roadmap update can be to narrow down the promising RDD responses and to upscale the emergent ones.

7.5 Chapter summary

The socioeconomic transitions for the three sectors investigated in this chapter show the economic climate as a common innovation landscape factor that is incorporated into the South African technology roadmaps. The obvious reason for the inclusion of economic climate is the fact that technology roadmaps are used to mobilise the resource commitment from the relevant stakeholders (McDowall, 2012). The government policy and social discourse are also the critical innovation landscape factors that affect success of South African technology roadmaps in the selected three sectors. This observation is in



agreement with Ogura (2016) for the need to develop a political roadmap alongside the technical roadmap. The evolution of public discourse on national issues as discussed by Rivoli & Waddock (2011) shows the various phases that can present a window of opportunity for the niche innovators.

The multiple emerging technologies were shown to be a case for three types of case technology roadmaps presented in this chapter. In the case of the energy sector, the multiple emerging technologies are mainly the renewable energy technologies such as the hydrogen energy storage, wind energy, solar energy and nuclear energy. In addition, the incumbents within the coal industry are also investigating the new technologies such as CCS in order to sustain their dominance. The adaptation of the coal industry to the changing innovation landscape (requirements for the reduction of CO₂ emissions) and the increase in competition from the renewable energy niche innovators is characteristic of the complex innovation system.

In all three sectors, the choice of products and technologies that are the focus of technology roadmaps is tentative and it depends on the learning derived as the technology roadmap is implemented. The mining technology roadmap has a set of multiple technologies that can be accelerated or decelerated as the technology roadmap is implemented. The same applies to the Water RDI Roadmap which has seven RDD responses that are driven through the WADER programme. These R&D responses are not concrete, a characteristic of the predevelopment stage for the proposed transition-based technology roadmap.

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CHAPTER 8: CONCLUSIONS AND RECOMMENDED FUTURE WORK

8.1 Introduction

At the conceptualisation of this study less was known about the fourth industrial revolution, a concept that was popularised during the 2016 World Economic Forum annual meeting at Davos, Switzerland. As it has been shown, the technology roadmapping framework for complex innovation environments in developing countries, deduced out of this study, is also relevant to third generation technology roadmaps. The third generation technology roadmap is an ideal technology future planning approach that is suitable for multiple emerging technologies associated with the fourth industrial revolution.

This chapter reflects on coverage and answering of research questions, theoretical and managerial implications, research limitations and suggested future research. The theoretical framework in chapter 3 laid a foundation for answering of the research questions. The analytical propositions were deduced from quantitative survey responses with the assistance of the input from qualitative surveys and content analysis of accessible technology roadmap documents.

8.2 Coverage and answering of the research questions

Table 8.1 shows the ten analytical propositions developed to address the two main research questions, namely: i) the unique framework conditions for innovation in developing countries and ii) whether technology roadmapping practices can be adapted for developing countries' framework conditions. For the first main question, the research sub-questions are 1) identification of the main priorities for innovation in South Africa and 2) identification of actual/perceived innovation competitive advantages for South Africa.

**Table 8.1: Summary of the research questions and relevant propositions**

Main Research Question	Research Sub-Questions	Deduced Propositions
What are the unique framework conditions for innovation in developing countries?	What are the main priorities for innovation in South Africa?	1. The main innovation priority for technology roadmaps in developing countries is science-driven technological capability development 2. The main innovation priority for technology roadmaps of private sector companies in developing countries is technology development and market integration
	What are the actual or perceived innovation competitive advantages for South Africa?	3. External networks of partners are valuable sources of competitive advantage for innovation programmes that are part of technology roadmaps in developing countries 4. Timing of the innovation landscape's window of opportunity is important for technology roadmapping in developing countries in order to create the innovation competitive advantage 5. Novel innovation pathways are likely to result from technology roadmap innovation programmes that make use of biotechnology, nanotechnology and environmental technologies.
Can technology roadmapping practice be adapted for developing countries' framework conditions?	What is the nature and characteristics of technology roadmaps in South Africa?	6. Third generation technology roadmaps are dominant in developing countries 7. Private sector technology roadmaps in developing countries are geared more towards technology leapfrogging in relation to the public sector technology roadmaps
	What are the critical factors for successful technology roadmaps in South Africa?	8. In developing transition-based technology roadmaps for developing countries there should be a balance between involvements of stakeholders from a dominant product-technology platform and those who seek new modes of innovation 9. Scenario planning is an appropriate technique to use for selection of technologies and products that are part of technology roadmaps in developing countries 10. Monitoring and update of technology roadmaps are critically important for transition-based roadmaps at developing countries, and such functions should be championed by the owners of the roadmap



The first two propositions address the first research sub-question with the analytical inferences that i) the main innovation priority for technology roadmaps in developing countries is technological capability development and a proposition that ii) the main innovation priority for technology roadmaps of private sector companies in developing countries is technology and market integration. As will be the case for other research sub-questions that follow, these analytical propositions are only the key issues extracted and there is plenty of other relevant issues in the discussion sections.

Propositions 3 to 5 respond to the second research sub-question about the actual/ perceived innovation competitive advantages for South Africa. These competitive advantages include issues such as the innovation ecosystem through an external network of partners, timing of innovation landscape's window of opportunity as well as adoption of novel innovation pathways through emerging technologies such as biotechnology, nanotechnology and environmental technologies.

The research sub-questions associated with the second main research question concerns 1) the nature and characteristics of technology roadmaps in South Africa and 2) the critical factors for successful technology roadmaps in South Africa. For research sub-question 3, proposition 6 makes a case for third generation technology roadmaps being dominant in developing countries whereas proposition 7 suggests that private sector technology roadmaps at developing countries are more geared towards technology leapfrogging in relation to public sector technology roadmaps.

The three analytical propositions that address the research sub-question of critical factors for successful technology roadmaps in South Africa cover issues such i) balance between involvement of stakeholders from dominant product-technology platform and those who seek new order; ii) the use of scenario planning for selection of technologies and products that are part of technology roadmaps in developing countries; and iii) regular monitoring and update of



technology roadmaps in order to guide transition stages of predevelopment, take-off, upscaling and stabilisation.

8.3 Summary of transition-based technology roadmapping process for the developing countries

The framework for technology roadmapping in developing countries addresses both the roadmapping process and format for visualisation of the roadmap. The roadmapping process adopts the generic one proposed by Garcia & Bray (1997). A reference was made in section 3.6 that there is nothing wrong with the utilisation of technology roadmapping techniques, but rather with a blind application of these techniques in cases such as a disruptive technology base (Walsh, 2004). The structure of the roadmapping process is not tempered with, although it is suggested to incorporate the concepts such as transition management, complex systems and leapfrogging (preliminary activities); niche experimentation, blue ocean strategy, strategy canvas, technology prioritisation and emerging technologies (technology roadmap development); and learning-by-doing by keeping a roadmap live (follow-up activities). As a result, one can also make use of the T-Plan, S-Plan and IEA technology roadmapping processes for the transition technology roadmaps. The following is a step by step guideline for transition-based technology roadmapping process:

Phase 1: Preliminary Activities

As shown in the literature review (sub-section 2.2.3), there many variations of the preliminary activity steps that can be used, depending on the context. Propositions 1 and 2 captures the two roadmapping perspectives, namely technology and research perspective by the public sector as well as the commercial & strategic and design, development & production perspectives by the private sector. The following principles can be taken into account during the preliminary activities:

1. **Satisfy essential conditions:** making sure that there is a clear case for the transition from the current dominant innovation regime to a desired



future state. Situation analysis of the roadmapping organisation or the beneficiary organisation is important to understanding the current or potential organisational capabilities versus that of the incumbents and to assess the window of opportunity within the innovation landscape (proposition 4).

2. ***Provide leadership and sponsorship***: the successful technology roadmapping steering committees are those that are formed with the external partners. Proposition 3 provides a recommendation for the involvement of the external network of partners. However, one should take into account the transition objective and the influence of the three layers of a complex innovation system (innovation landscape, dominant innovation regime and niche innovators). Proposition 8 suggests that there should be a balance between an involvement of stakeholders from a dominant product-technology platform and those who seek new modes of innovation. The leadership for the technology roadmap is also linked to the sponsorship type as it has been shown that the type of a roadmap sponsor influences the focus and the scope for the roadmap. The executive leadership should articulate the long-term vision and strategic objectives of the roadmapping organisation, industry, etc.
3. ***Define scope and boundaries for the technology roadmap***: the scope of the roadmap should include a relatively longer time line, which is typically 20 – 25 years for the transition-based technology roadmaps, although the private sector organisations might seek to leapfrog through a relatively shorter time period (proposition 7), provided that the leapfrogging conditions are fulfilled as suggested by Perkins (2003). The scope and boundaries should be explicit about a paradigm shift being sought, namely: incremental innovation on the existing product technology platform, insertion of emerging technology or roadmapping of multiple emerging technologies. The latter is preferred for the transition-based third generation technology roadmaps (proposition 6).



Phase 2: Technology Roadmap Development

1. **Identify the products that will be the focus of the roadmap:** identification of promising technology product platforms (niche innovations) and grand challenges. As this exercise is carried out, one need to be mindful of the dominant product technology platform and the structure of an existing innovation value-chain. Scenario planning can also be useful on this step (proposition 9).
2. **Identify the critical system requirements and their targets:** the blue-ocean strategic management tools such as the strategy canvas can help in identifying the critical system requirements and their targets for the niche innovations. Strategy canvas maps opportunities resulting from a gap between dominant product or services offered and the customer needs.
3. **Specify the major technology areas:** in identifying the technology areas, the emerging technologies on areas such as biotechnology, nanotechnology and environmental technologies are ideal for the novel innovation pathways (proposition 5).
4. **Specify the technology drivers and their targets:** technology drivers relate to how the technology addresses the critical system requirement targets and they are the critical variables that will determine which technology alternatives are selected (Garcia & Bray, 1997). The technology drivers need to factor-in the organisation's objectives.
5. **Identify technology alternatives and their time lines:** a set of scenarios need to be developed based on technology drivers and their valuation as well as the associated assumptions (proposition 9). As these scenarios unfold, niche technologies need to prove themselves as a viable alternative in order to be supported for upscaling.
6. **Recommend the technology alternatives that should be pursued:** the selection of technology alternatives should take into account the organisation's objectives, transition objectives and a cost-benefit tradeoff.



7. **Create the technology roadmap report:** the proposed transition-based technology roadmap format is recommended for a high-level visualisation of the roadmap (Figure 3.2).

Phase 3: Follow-up Activities

1. **Critique and validate the roadmap:** fine-tuning of the technology roadmap assumptions through consultation of the stakeholders, even those who are entrenched on a dominant product technology platform.
2. **Develop an implementation plan:** high degree of flexibility to adapt to the changes in innovation landscape and for the possible response by the incumbents (learning by doing). Executive support is necessary for success of the roadmap implementation.
3. **Review and update the roadmap:** the technology management tools such as the phase gate model can be used to review the evolution of roadmap implementation through various transition phases, namely: predevelopment, take-off, upscaling and stabilisation. Proposition 10 mentions a need for the involvement of roadmapping owners for its monitoring and update.

8.4 Contribution of this research

The contributions of this research are twofold in terms of both technology roadmapping literature and practice. A first theoretical contribution relates to the integration of the technology roadmapping framework with other knowledge domains such as transition management theory, complex systems theory and innovation value chain upgrading theory. According to Phaal, Farrukh & Probert (2004), there may be benefits in ensuring that the structure of the roadmap integrates with other approaches and systems.

There are several frameworks in the literature that also attempted to achieve this integration. Some examples of such combinations are technology roadmapping and transition management theory (Dixon et al., 2014; McDowall, 2012) as well



as technology roadmapping and complex systems theory (Kamtsiou, 2016; Phaal et al., 2011). However, there is not yet any known study that integrated all these frameworks together with a technology roadmapping framework, especially for developing countries.

A second theoretical contribution relates to the increase in the body of knowledge in relation to a relatively new generation of technology roadmap. As suggested by proposition 6, third generation technology roadmaps, which involves converging multiple technologies, are dominant in developing countries.

Few scholars have investigated frameworks for development of third generation technology roadmaps although there is an interest of discoveries about what these roadmaps entail. According to Marinakis & Walsh (2016), the third generation technology roadmap is a 'roadmap of roadmaps' or a meta roadmap that is designed for use with contemporary technological systems that comprise multiple root technologies at various technology readiness levels. The fourth industrial revolution involves convergence of multiple emerging technologies that are collectively called cyber-physical systems (Lee, Bagheri & Kao, 2014), hence third generation technology roadmaps are more relevant to this wave of the industrial revolution. Indeed, this work provides a first overview of the relationship between technology roadmaps and the fourth industrial revolution.

In addition to theoretical contributions, the outcomes of this research contribute to technology roadmapping practice in developing countries in terms of format and the roadmapping process. The proposed transition-based technology roadmap format concretise the idea of Marinakis & Walsh (2016) regarding third generation technology roadmap being a 'roadmap of the roadmaps'. These roadmaps involve niche experimentation through the use of emerging technologies. Other experts have also suggested the use of emerging technology scenarios in place of a series of roadmaps for niche experimentation. Analytical propositions 8 – 10 practically guides stages of technology roadmap



development in developing countries, namely: preliminary activities, technology roadmap development and follow-up activities.

8.5 Limitations of this research

A first limitation relates to a limited set of data available due to a relatively small population, which is further complicated by a potential 'hidden population' for private sector technology roadmapping activities in South Africa. As shown, this limitation is addressed through the mixed method research approach in order to bring together the strength of various techniques. As most respondents who take part in technology roadmapping activities are often involved in several roadmapping activities, the referral advantage is secured as shown by an enhanced profile of respondents who completed a quantitative survey in comparison to a sample list compiled.

The second limitation of this study relates to the complex nature of innovation dynamics in South Africa and other developing countries. The respondents might not be aware of factors influencing their world views as reflected by uncertainty in some of their responses. A type of research design adopted for this study attempts to address and acknowledge this complexity. Critical realism research philosophy takes note of the fact that there might be extraneous variables that might affect the causal inference of the research findings, although they do not form part of the empirical research (Shek, 2013). This research design adopts an agile approach and it is acknowledged that another researcher might need to customise/ improve the framework developed/ analytical propositions of this study to accommodate the extraneous variables that might be dominant within the investigation environment.

8.6 Generalisation of the findings to other developing countries

In alignment to the stated research objectives and associated research questions, the inference out of the findings of this study is at the level of developing countries. This raises certain challenges regarding this generalisation for developing countries, since the data that was used to deduce



the 10 analytical propositions was collected only in South Africa. In addition, there are various types of developing countries, namely: low income developing countries, middle income developing countries and newly industrialised countries (Littlewood & Yousuf, 2000; Butt, 2017).

The literature on comparative research designs shows the possible three designs that can be used for comparison across different countries or cultures, namely: many-country comparison, few-country comparison and a single-country comparison (Lor, 2012). According to Lor, in variable-oriented comparative studies many countries are studied. For case-orientated studies, a single country or a small number of countries is/ are studied.

Although South Africa is classified as an upper-middle income developing country (Ozturk, Aslan & Kalyoncu, 2010), some analysts have pointed to the danger of averaging the economy. In fact, South Africa is often classified as a dual economy (Devey, Skinner and Valodia, 2006; Calof & Viviers, 1995) due to the legacy of apartheid, an old system of racial segregation. Some pockets of excellence around industrialisation are the chemical sector in which South Africa has high comparative advantage (NACI, 2015). As a result, South Africa displays a mix of low income, middle income and newly industrialised countries' characteristics.

It follows therefore that the findings of this study can easily be externalised to various type of developing countries. According to Landman (2008), for a single-country comparative study, an important factor is the choice of a case country and such a country can be chosen because it is considered to represent a category or group of countries.

At individual level, most of the deduced analytical propositions out of this study are in agreement with the relevant literature. For example, the work of Watson et al. (2015) analysed the development of China's technological capabilities via a strategic approach for low carbon technology transfer and development. There is a plethora of other studies that are in agreement with proposition 1 regarding



the main priority of developing countries as technological capability development (Xianjun, Ke & Li, 2009; Hansen & Ockwell, 2014).

Similarly, a study by Chan (2013) has a high level of agreement with propositions 4, 5 and 7 regarding a window of opportunity, novel innovation pathways resulting from emerging technologies and technology leapfrogging. This study emphasise the role of emerging technologies in providing the window of opportunity for technology leapfrogging in developing countries such as China. The author mentions emerging technologies such as nanotechnology, biotechnology and information technology as having potential to provide such a window of opportunity. This is partly in agreement to proposition 5 although the main difference is information technology in place of environmental technologies. Therefore proposition 5 just provides a guideline for the developing countries that seek the novel innovation pathways, although each country's strengths and priorities still need to be considered in selecting the technologies that are part of a technology roadmap.

8.7 Recommended future research

The first area of future research involves improvement in research methodology to deal with a challenge of hidden populations, especially for private sector technology roadmapping practitioners. Some sampling techniques that can deal with this problem include snowball sampling and respondent-driven sampling (RDS). Snowball sampling entails identifying an initial number of subgroup members from whom desired data is gathered and who then serve as 'seeds' to help identify other subgroup members to be included on the improved sample list (Magnani et al., 2005). This process can be continued until the target sample is reached or until the sample becomes saturated.

According to Crawford, Wu & Heimer (2017), snowball sampling doesn't always yield the results as social contacts of an initial set of respondents might decline to enrol in the study. In cases where this is a problem, other chain-referral methods such as RDS become useful. RDS is a series of sampling methods that



have as their common goal an effort to convert chain-referral sampling into a sampling method of good estimability (Heckathorn, 2011). These improved sampling methods could assist with the problem of statistical inference which can be achieved through the conversion of the deduced analytical propositions into research hypotheses. Pure theory testing of fully developed hypotheses is a logical step following theory refinement through qualitative explanatory study (van Echtelt et al., 2008).

Technology roadmapping literature has various techniques available for development of roadmaps. These include the S-Plan and T-Plan fast-start approaches (Phaal & Palmer, 2010), strategic technology alignment roadmapping (Gindy et al., 2008), technology development envelope (Gerdri & Kocaoglu, 2007), etc. Unfortunately such techniques might not be relevant to the development of third generation technology roadmaps for developing countries. Further research is therefore needed for development of technology roadmapping practical tools for third generation technology roadmaps.

8.8 References

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APPENDIX A: RESEARCH INSTRUMENTS

A.1 Ethics approval



Faculty of Engineering,
Built Environment and Information Technology

1956 – 2016
60
years of
Engineering Education

Reference number: EBIT/06/2016

18 April 2016

Mr TP Letaba
Department GSTM
University of Pretoria
Pretoria
0028

Dear Mr Letaba,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Ethics Committee refers.

1. I hereby wish to inform you that the research project titled "Complex technology roadmaps development in a context of developing countries" has been approved provisionally by the Committee. If video/voice recording is to be used during interview, consent needs to be obtained from the participants. If this is the case, please update the informed consent form accordingly.

This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Codes of Research Ethics of the University of Pretoria, if action is taken beyond the approved proposal.

2. According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of any member of the Faculty Committee who will deal with the matter.
3. The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof JJ Hanekom

Chair: Faculty Committee for Research Ethics and Integrity

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY



A.2 Informed consent form

**Informed consent form
(Form for research subject's permission)**

(Must be signed by each research subject, and must be kept on record by the researcher)

- 1 Title of research project: *Complex Technology Roadmaps Development in a Context of Developing Countries*
- 2 I hereby voluntarily grant my permission for participation in the project as explained to me by ...*Petrus Letaba*.....
- 3 The nature, objective, possible safety and health implications have been explained to me and I understand them.
- 4 I understand my right to choose whether to participate in the project and that the information furnished will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication.
- 5 I understand that in case of qualitative interviews, the interview can be recorded for the purpose of this research only.
- 6 Upon signature of this form, I will be provided with a copy.

Signed: _____ Date: _____

Witness: _____ Date: _____

Researcher: _____ Date: _____



A.3 Letters of permission to conduct research

A.3.1 CSIR permission

From: Daniel Visser [DVisser@csir.co.za]
Sent: 15 February 2016 10:25 AM
To: Petrus Letaba
Cc: Neil Trollip; tinus.pretorius@up.ac.za
Subject: RE: Permission to conduct research

Dear Mr Letaba

I am responding on behalf of Dr Sibisi regarding your request to conduct research. Permission for the study is granted provided necessary ethical considerations are taken into account as stipulated in your request.

Dr Neil Trollip (Copied here) has agreed to be a point of contact at the CSIR. Please contact him regarding participants to approach for the survey.

Kind Regards
Daniel

Dr Daniel Visser
R&D Strategy Manager
CSIR
Tel: +27 (0)12 841 2167
Cell: +27 (0)83 564 9161



A.3.2 Department of Science and Technology permission



Private Bag X894, Pretoria, 0001 Tel.: +27 (0)12 843 8710 Fax: +27 (0)86 681 0025 www.dst.gov.za

Mr Petrus Letaba
Senior Specialist
NACI

Dear Mr Letaba

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH

This serves as acknowledgement of receipt of your request to conduct research at the Department of Science and Technology on the following topic:

"Complex Technology Roadmaps Development in a Context of Developing Countries."

Please note that approval of your request is granted on condition that adherence to terms of confidentiality and information security as required by the Department is maintained at all times.

Yours sincerely,

MODIBEDI, N
CHIEF DIRECTOR: HR

Date: 18/05/16



A.3.3 Department of Trade and Industry permission



Private Bag X84, PRETORIA, 0001, the dti Campus, 77 Meintjies Street, Sunnyside, 0002. Tel: (012) 394 0000
the dti Customer Contact Centre local: 0861 843 384 International: +27 12 394 9500. www.thedti.gov.za

Enquiries: Leighanne Naicker
Telephone: (012) 394 3577
E-mail: L.Naicker@thedti.gov.za

Mr Petrus Letaba
48 Matterson Street
Kilner Park
0186

Dear Mr Letaba

RE: REQUEST FOR APPROVAL TO CONDUCT RESEARCH AT the dti

Your submission requesting approval to conduct research at the Department of Trade and Industry (the dti) refers.

the dti is in support of your research towards an investigation of the suitability of the current technology roadmapping methodologies for developing countries and is willing to provide you with the necessary support to make the project a success. We trust that the recommendation you will provide will contribute to a sound framework for technology roadmapping for developing countries.

Kindly note that approval has been granted on the following conditions:

- That you complete a Confidentiality Declaration form to ensure compliance with Departmental policies;
- That you participate in a briefing discussion with the Vetting Unit before commencement of the research;
- That you provide the dti with a detailed research plan and draft questionnaires, surveys and/or interview questionnaires (where applicable); and
- That you submit a copy of your research report once you have published the final document.

Should you have any further enquiries regarding the content herein, please contact the Director: Human Resource Development, Ms Angie Ontong on 012 394 5980 or email AOntong@thedti.gov.za.

Yours sincerely,

LIONEL OCTOBER
DIRECTOR-GENERAL

DATE: 18/03/16





A.4 Quantitative survey questionnaire

Technology Roadmapping Practice in South Africa

Survey Cover Letter

Dear Participant,

This survey is part of my PhD studies at the University of Pretoria, Graduate School of Technology Management. The topic of research is "Complex Technology Roadmaps Development in a Context of Developing Countries". I am inviting you to take part in this survey by completing this online questionnaire because of your previous/ current involvement in technology roadmapping activities in South Africa. A sample of respondents from the government, state owned enterprises, large companies and the SMEs were selected based on various information sources such as Google, LinkedIn, publicly available information on companies' documents and websites, etc.

The questionnaire is divided into three sections: Part A is general information about the respondents, Part B has questions on the innovation dynamics which is the focus of technology roadmaps developed/ being developed and Part C has questions on technology roadmaps development and the nature of TRMs.

The questionnaire should take approximately 20 minutes of your time. You can edit your survey response any time before the 30 June 2016, a due date for the responses. The information collected will be used only at an aggregated level for academic purpose (journal/ conference publications and PhD research report). All care will be taken to protect the identity of the respondents.

For your convenience, a list of general definitions is shown on the next page and other definitions specific to certain questions are displayed next to those questions.



Informed Consent Form

Title of research project: **Complex Technology Roadmaps Development in a Context of Developing Countries.**

I hereby voluntarily grant my permission for participation in the project as explained to me by **Petrus Letaba**.

The nature, objective, possible safety and health implications have been explained to me and I understand them.

I understand my right to choose whether to participate in the project and that the information furnished will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication.

If you answer no to the following question, you will not be able to proceed with the rest of the survey

1. Informed Consent Provided:

Yes

No

General Definitions

1. Technology Roadmapping

A technology planning process that helps to identify, select and develop technology alternatives to satisfy a set of product/ market needs. It is relatively a long range plan in comparison to forecasting and foresight methods.

2. Technology Roadmap



An output/ document that is generated by the technology roadmapping process. A generic format is typically sequential layers of R&D, technology, products, and market on the vertical axis and the time scale on the horizontal axis.

3. Technology

The use of scientific knowledge to solve practical problems, especially in industry and commerce; and also the specific methods, materials, and devices used to solve practical problems, e.g. aerospace technology.

4. Innovation

The development and commercialisation of all new combinations based on the application of: new materials and components; the introduction of new processes; the opening of new markets; and the introduction of new organisational forms.

5. Emerging Technologies

Newly developed technologies that have ability to disrupt or sustain current products/ industries. They can be incremental or radical in nature.

Part A: General Information

* 2. Do you have experience in long-range strategy planning exercise (s) in which future technology requirements are matched to the products/ market needs?

Yes

No

* 3. In which country did you take part/ experience this long-range strategy planning exercise in which future technology requirements are matched to the products/ market needs?



* 4. Where did you participate/ experience technology roadmapping exercise?

- Current Organisation
- Previous Organisation
- Partner Organisation
- Other (please specify)

* 5. What is your approximate experience in years for participating in technology roadmapping activities?

- less than 1 year
- between 1 and 3 years
- between 3 and 5 years
- between 5 and 7 years
- between 7 and 10 years
- more than 10 years

Part B: Innovation Dynamics

Since a technology roadmap is viewed as a strategic lens, through which a complex innovation system can be viewed, the researchers through this section intend to understand the innovation programme issues being addressed by technology roadmaps developed/ being developed. Therefore in answering this section (Part B), the respondents are requested to answer the questions in relation to the market, products, technologies that are/ were the focus of the roadmap in which they are familiar with.



Main Priorities for Innovation

* 6. On the innovation based programmes/ projects that you are/ were involved with, and which are/ were the main focus for technology roadmapping exercise you are/ were involved with, what is/ was the main focus?

- Basic and/ or Applied Research
- Technological Development
- Product Development/ Manufacturing
- Process Development
- Service Offering
- Market Development/ Entrepreneurship
- Technology Localisation and Adaptation
- Other (please specify)

* 7. What is/ are the likely impact of these innovation based programmes/ projects?

- Research Capacity Development
- Technological Capacity Development
- Manufacturing Capacity Development
- Process Capacity Development
- Costs Efficiency
- Market Competitiveness
- Global Competitiveness
- Social Impact at the Country Level
- Economic Impact at the Country Level
- Other (please specify)



* 8. What are the main innovation landscape factors that are positively influencing your innovation based programmes/ projects?

- Good Culture of Innovation
- Access to Natural Resources
- Strong Research and Development Capacity
- Favourable Intellectual Property Protection Laws
- Funding Availability
- Strong Technical/ Engineering Capacity
- Competition from Other Companies/ Countries
- Valuable Network of Partners
- Good Entrepreneurial Culture
- Political Willingness
- Other (please specify)

* 9. What are the main innovation landscape factors that are negatively influencing these innovation based programmes/ projects?



- Poor Culture of Innovation
- Lack of Access to Natural Resources
- Weak Research and Development Capacity
- Unfavourable Intellectual Property Protection Laws
- Lack of Funding
- Weak Technical/ Engineering Capacity
- Competition from Other Companies/ Countries
- Lack of Relevant Partners
- Lack of Entrepreneurial Culture
- Lack of Political Willingness
- Other (please specify)

Opportunities Presented by Emerging Technologies

10. Which emerging technologies are part of the innovation programmes/ projects that are/ were part of technology roadmapping exercise?

- Biotechnology
- Nanotechnology
- Renewable Energy
- Big Data/ Internet of Things
- Robotics/ Automation
- Photonics
- 3D and/ or 4D Printing
- Environmental Technologies
- Aerostructures
- Other (please specify)



11. How were these emerging technologies selected?

- Future Proven/ Anticipated Value
- Available Research Capacity
- Available Engineering/ Manufacturing Capacity
- Responding to Market Need
- Responding to Societal Needs
- Aligning to Global Trend
- Relevance to the Country
- Other (please specify)

12. How will these emerging technologies add value?

- New Industry Creation
- Improvement of the Industry
- New Products Development
- Improvement of Existing Products
- Increase in Exports
- Improvement of Processes
- Other (please specify)

Part C: Technology Roadmaps Format and Roadmapping Process

Nature and Characteristics of Technology Roadmaps



*13. What is the type of organisation (s) in which you participated for technology roadmapping activities?

- Government
- State Owned Enterprise
- Large Company
- SME
- Not-for-Profit Organisation
- Industry Association
- International Organisation in South Africa
- Science Council
- International Organisation Outside of South Africa
- Other (please specify)

*14. These technology roadmapping activities are/ were intended for which type of industry (ies)?

- Agriculture, Forestry & Fishing
- Mining & Quarrying
- Manufacturing
- Electricity, Gas and Water Supply
- Construction
- Wholesale and Retail Trade; Repair of Motor Vehicles, Motor Cycles and Personal and Household Goods; Hotels and Restaurants
- Transport, Storage and Communication
- Financial Intermediation Insurance, Real Estate and Business Services
- Community, Social and Personal Services
- General Government



*15. What is an average planning horizon for these technology roadmaps?

- Less than 5 Years
- Between 5 and 10 Years
- Between 10 and 15 Years
- Between 15 and 20 Years
- Between 20 and 25 Years
- More than 25 Years

*16. Typically, what are these technology roadmaps focusing towards?

- Research and Development (R&D) Agenda Setting
- Technology Platform Development
- Product (s) Platform/ Service Offering Development
- Market Development
- R&D and Market Integration
- Technology Development and Market Integration
- Technology Development and Products/ Process/ Service Offering Integration
- R&D and Technology Development Integration
- Products/ Process/ Service Offering Development and Market Integration
- Other (please specify)



* 17. What is the main usage for these technology roadmaps?

As a Tool for Development of Strategy/ Policy

As a Strategy/ Policy Implementation Tool

Other (please specify)

* 18. How best would you rank the purpose of these technology roadmaps? [1 is the highest rank]

☰ Incremental Innovation on a Stable Product Technoloav

☰ Insertion of Emeraina Technoloaies on Existina

☰ Plannina for Multiple Converaina/ Competina

* 19. Are the technology roadmaps that you are familiar with linked/ integrated with other roadmaps across various divisions/ departments of the organisation/ government?

Yes

No

Not Sure

20. Are these technology roadmaps linked/ integrated with the stakeholder planning processes outside of the organisation?

Yes

No

Not Sure



* 21. Do these technology roadmaps incorporate the influence of multinational corporations/ global trends on the innovation landscape?

Yes

No

Please elaborate:

* 22. Do these technology roadmaps incorporate the influence of any of the following factors? Please mark those applicable:

Culture

Political Climate

Legal Environment (e.g. IP Laws)

Economic Climate

Other Innovation Landscape Factors (please specify)

* 23. What other tools do you incorporate in technology roadmapping process?



Business Process Analysis

Portfolio Analysis

Lifecycle Analysis

Competitive Analysis

Capability Analysis

Delphi Technique

Workshops

Strategy Canvas

Ecosystem Analysis

Scenario Planning

Other (please specify)

Technology Roadmap Development Process

24. What type of structure is/ was put in place for development of these technology roadmaps?

Normal Organisational Operating Team

Central Organisational Strategic Planning Team

Formation of a New Division/ Organisation Wide Roadmapping Team/ Committee

Formation of a New Roadmapping Team/ Committee with External Partners

Other (please specify)



25. Who sponsors/ sponsored the technology roadmap development effort?

- Organisational Internal Funding
- Local Stakeholders (including industry associations)
- Government
- International Organisation (s)
- Other (please specify)

26. What type of consensus-making process is used during the development of these technology roadmaps?

- Desktop Study
- Forecasting Methods
- Expert (s) Judgement
- Workshop (s)
- Vote by Key Stakeholders
- Other (please specify)

* 27. Which criteria is used to select the products/ programmes and technologies that will be the focus of technology roadmap? Based on:



- Proven R&D Outputs (internal/ partners)
- Technology Maturity Level (internal/ partners)
- Existing Manufacturing Capacity (internal/ partners)
- Market/ Stakeholders/ Societal Needs
- Other (please specify)

Success Level and Critical Factors for the Successful Technology Roadmaps

* 28. Is the technology roadmapping committee/ structure kept functioning after the initial approval of the roadmap?

- Yes
- No
- Not Sure

Please elaborate:

* 29. If you answered yes to Q28, what is/ are the ongoing function (s) of technology roadmapping committee/ structure?



- Monitoring of the Roadmap
- Implementation of the Roadmap
- Update of the Roadmap
- Other (please

* 30. Who monitors the success level of these technology roadmaps?

- Technology Roadmapping Committee/ Team
- Internal Structure (not involved with technology roadmap development)
- Peer Review Mechanism by External Stakeholder
- Appointed Service Provider
- Technology Roadmapping Sponsor
- Other (please specify)

* 31. Overall, how are these technology roadmaps being utilised for?

- Once-off Exercise. Roadmap Actions not Implemented
- Roadmap Actions are Implemented Narrowly (not integrated across organisation/ industry/ government)
- Roadmap Actions are Implemented Broadly Across the Organisation/ Industry/ Government

Please elaborate:



32. What have been the key factors for success of these technology roadmaps?

- Executive Support
- Internal Buy-in by Staff
- External Buy-in by Stakeholders
- Continued Existence of Roadmapping Team/ Committee
- Sufficient Capacity to Implement the Roadmap
- The Roadmap is Kept Alive/ Updated
- The Roadmap Address the Key Strategic Issues
- Other (please specify)

33. What have been the key factors for failure of these technology roadmaps?

- Lack of Executive Support
- Lack of Internal Buy-in by Staff
- The Roadmapping was a Once-Off Process
- The Roadmap is not Kept Alive/ Updated
- The Roadmap is Unrealistic
- Other (please specify)



34. Do you have an example (s) of these technology roadmaps that can be made available to us on request?

Yes

No

More details (please specify)

35. In your opinion, what can be done to improve the development of technology roadmaps, especially for developing countries?

36. In your opinion, what can be done to improve the impact of technology roadmaps?

Acknowledgement Page

Thank you very much for your valued time in completing this survey.



A.5 Qualitative interviews questionnaire

1. General Questions

1.1. Have you ever participated on long-range strategic planning process in which future technology requirements are matched to the products/ market needs?

If yes,

1.1.1. In which country?

1.1.2. What is your approximate experience in years for participating in these type of activities?

1.1.3. What was your role for this long range planning?

2. Innovation Programmes' Competitive Advantage

2.1. For the innovation programme (s) that was/ were part of technology roadmaps that you participated for, which national/ macro factors (e.g. political, economic, social and legal) had positive influence and which had negative influence?

2.2. For the innovation programme (s) that was/ were part of technology roadmaps that you participated for, which industry/ meso factors (e.g. network of partners, funding and competition) had positive influence and which had negative influence?

2.2.1. What is the extent and impact of competition (at national, industrial or firm level) both locally and globally for innovation programmes that are/ were part of technology roadmap (s)?

2.3. For the innovation programme (s) that was/ were part of technology roadmaps that you participated for, which organisational/ micro factors had positive influence and which had negative influence?



3. Opportunities from Emerging Technologies

- 3.1. Which emerging technologies were part of technology roadmaps that you participated for?
- 3.2. Are these technologies incorporated into the final technology roadmap document (s)?
- 3.3. What is an anticipated impact of these emerging technologies?

4. Nature of Technology Roadmaps in South Africa

- 4.1. Are the focus of technology roadmaps that you were part of/ familiar with accurately represent what the innovation programme seek to address? (*Note: Technology Roadmaps are Visual Representation/ Strategic Lens of Innovation Dynamics*)
- 4.2. Are the technology roadmaps that you were part of/ familiar with integrated with other internal roadmaps?
 - 4.2.1. How are they related?
- 4.3. Are the technology roadmaps that you were part of/ familiar with integrated with external plans of the stakeholders?
 - 4.3.1. How are they related with these external plans?

5. Development of Technology Roadmaps in South Africa

- 5.1. Who sponsored the development of technology roadmaps?
 - 5.1.1. To what extent the sponsor affected the nature of consensus making method during technology roadmap development?

6. Success Level of Technology Roadmaps in South Africa



- 6.1. What is the nature of structure that was put in place for development of technology roadmaps?
 - 6.1.1. What is the on-going responsibilities for this structure (*e.g. update, monitoring or implementation of technology roadmap*)
- 6.2. Is there sufficient effort being dedicated for update of technology roadmap? Please elaborate.
- 6.3. How has lack of executive support influence success/ failure of technology roadmaps?

7. Success Level of Technology Roadmaps in South Africa

- 7.1. What are the critical factors for success of technology roadmaps in South Africa? Please elaborate.

APPENDIX B: QUANTITATIVE SURVEY RESULTS

General Information

Table B1: individual respondents' information

Respondent	TRM Experience	TRM Country	TRM Organisation	# of Part A Questions Completed	# of Part B Questions Completed	# of Part C Questions Completed
1	5 - 7 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q18 Q21 to Q27 Q31 to Q34
2	1 - 3 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q34
3	5 - 7 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q34
4	1 - 3 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q27 Q30, Q32, Q34
5	1 - 3 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
6	More than 10 years	South Africa, UK	Current and Previous Organisation	Q2 to Q5	Q6 to Q12	-
7	5 - 7 years	South Africa	Current Organisation Partner organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
8	3 - 5 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
9	5 - 7 years	South Africa, Europe	Current Organisation	Q2 to Q5	Q6 to Q9	-
10	5 - 7 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
11	7 - 10 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
12	More than 10 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
13	More than 10 years	South Africa	Current Organisation	Q2 to Q5	Q6 to Q12	Q13 to Q36
14	More than 10 years	South Africa, Germany	Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
15	5 - 7 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
16	7 - 10 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
17	More than 10 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
18	3 - 5 years	South Africa	Partner Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
19	7 - 10 years	South Africa	Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
20	More than 10 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
21	3 - 5 years	South Africa, Australia, USA	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
22	3 - 5 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36

Complex technology roadmaps development in a context of developing countries



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23	1 - 3 years	South Africa	Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
24	7 - 10 years	South Africa, USA	Current and Partner Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q34
25	3 - 5 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
26	Less than 1 year	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
27	More than 10 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	-
28	Less than 1 year	-	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
29	More than 10 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
30	More than 10 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
31	More than 10 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36 (Q25 skipped)
32	7 - 10 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q34
33	5 - 7 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q34
34	3 - 5 years	South Africa	Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q27
35	3 - 5 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
36	More than 10 years	South Africa	Partner Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q27
37	1 - 3 years	South Africa	Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q34 (Q32 skipped)
38	1 - 3 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q34
39	3 - 5 years	South Africa	Current, Previous and Partner Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
40	1 - 3 years	South Africa	Current and Partner Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
41	More than 10 years	South Africa	Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
42	3 - 5 years	South Africa	Previous Organisation	Q1 to Q5	Q6 to Q12	-
43	5 - 7 years	South Africa	Current and Previous Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36
44	1 - 3 years	South Africa	Current Organisation	Q1 to Q5	Q6 to Q12	Q13 to Q36

Main Research Results:

Innovation Planning in Developing Countries in Terms of Priorities, Opportunities and Challenges:



Table B2: main priorities for innovation programmes that are the focus of technology roadmaps

	Number of Respondents	Percentage of Respondents (n=44)
Technology Development	31	70.5
Basic and/ or Applied Research	20	45.5
Product Development/ Manufacturing	16	36.4
Process Development	15	34.1
Market Development/ Entrepreneurship	15	34.1
Technology Localisation and Adaptation	13	29.5
Service Offering	10	22.7

Table B3: the likely impact for innovation programmes that are the focus of technology roadmaps

	Number of Respondents	Percentage of Respondents (n=44)
Technological Capability Development	28	63.6
Economic Impact at the Country Level	27	61.4
Research Capability Development	25	56.8
Market Competitiveness	24	54.5
Social Impact at the Country Level	22	50
Global Competitiveness	21	47.7
Costs Efficiency	15	34.1
Manufacturing Capability Development	12	27.3
Process Capability Development	12	27.3
Environmental Sustainability	2	4.5
Products Performance Improvement	1	2.3

Complex technology roadmaps development in a context of developing countries



Table B4: focus of technology roadmaps per roadmapping organisation type

	R&D Agenda Setting	Tech. Platform Dev.	Product Platform Dev.	Market Dev.	R&D and Market Integration	Tech. Dev. & Market Integration	Tech. Dev. & Products Integration	R&D & Tech. Dev. Integration	Products Dev. & Market Integration
Government	17 (94.4%)	13 (72.2%)	8 (44.4%)	6 (33.3%)	11 (61.1%)	12 (66.7%)	3 (16.7%)	8 (44.4%)	6 (33.3%)
State Owned Enterprise	11 (73.3%)	9 (60%)	5 (33.3%)	6 (40%)	6 (40%)	11 (73.3%)	3 (20%)	7 (46.7%)	5 (33.3%)
Large Company	6 (46.2%)	9 (69.2%)	8 (61.5%)	3 (23.1%)	6 (46.2%)	8 (61.5%)	6 (46.2%)	3 (23.1%)	5 (38.5%)
SME	7 (87.5%)	5 (62.5%)	5 (62.5%)	3 (37.5%)	5 (62.5%)	6 (75%)	1 (12.5%)	3 (37.5%)	4 (50%)
NPO	4 (80%)	2 (40%)	2 (40%)	2 (40%)	3 (60%)	3 (60%)	1 (20%)	1 (20%)	2 (40%)
Industry Association	7 (77.8%)	7 (77.8%)	6 (66.7%)	2 (22.2%)	6 (66.7%)	6 (66.7%)	3 (33.3%)	2 (22.2%)	3 (33.3%)
International Organisation in South Africa	7 (100%)	6 (85.7%)	1 (14.3%)	2 (28.6%)	5 (71.4%)	5 (71.4%)	-	4 (57.1%)	1 (14.3%)
International Organisation Outside of South Africa	6 (75%)	5 (62.5%)	2 (25%)	1 (12.5%)	4 (50%)	3 (37.5%)	2 (25%)	2 (25%)	2 (25%)
Science Council	16 (88.9%)	11 (61.1%)	6 (33.3%)	6 (33.3%)	10 (55.6%)	11 (61.1%)	6 (33.3%)	9 (50%)	5 (27.8%)
Higher Education Institution	4 (100%)	3 (75%)	1 (25%)	1 (25%)	2 (50%)	1 (25%)	1 (25%)	2 (50%)	1 (25%)
All Organisations	26 (66.7%)	24 (61.5%)	11 (28.2%)	12 (30.8%)	14 (35.9%)	19 (48.7%)	11 (28.2%)	14 (35.9%)	9 (23.1%)

Table B5: focus of technology roadmaps per target industry

	R&D Agenda Setting	Tech. Platform Dev.	Product Platform Dev.	Market Dev.	R&D and Market Integration	Tech. Dev. & Market Integration	Tech. Dev. & Products Integration	R&D & Tech. Dev. Integration	Products Dev. & Market Integration
Agriculture, Forestry and Fishing	9 (100%)	9 (88.9%)	3 (33.3%)	2 (22.2%)	6 (66.7%)	6 (66.7%)	1 (11.1%)	4 (44.4%)	1 (11.1%)
Mining and Quarrying	5 (71.4%)	6 (85.7%)	2 (28.6%)	2 (28.6%)	4 (57.1%)	6 (85.7%)	2 (28.6%)	3 (42.9%)	1 (14.3%)
Manufacturing	17 (81%)	16 (76.2%)	6 (28.6%)	6 (28.6%)	9 (42.9%)	9 (42.9%)	6 (28.6%)	8 (38.1%)	3 (14.3%)
Electricity, Gas and Water Supply	17 (100%)	16 (94.1%)	6 (35.3%)	6 (35.3%)	9 (52.9%)	9 (52.9%)	6 (35.3%)	8 (47.1%)	3 (17.6%)
Personal and Household Goods	-	1 (100%)	-	-	-	1 (100%)	-	1 (100%)	1 (100%)
Transport, Storage and Communication	6 (67.7%)	4 (44.4%)	4 (44.4%)	4 (44.4%)	4 (44.4%)	5 (55.6%)	3 (33.3%)	5 (55.6%)	3 (33.3%)
Financial Services	-	1 (100%)	1 (100%)	-	-	-	1 (100%)	-	-
Community, Social and Personal Services	3 (100%)	3 (100%)	1 (33.3%)	1 (33.3%)	2 (66.7%)	1 (33.3%)	-	2 (66.7%)	2 (66.7%)
General Government	7 (70%)	6 (60%)	4 (40%)	3 (30%)	5 (50%)	5 (50%)	2 (20%)	5 (50%)	4 (40%)
All Target Industries	26 (66.7%)	24 (61.5%)	11 (28.2%)	12 (30.8%)	14 (35.9%)	19 (48.7%)	11 (28.2%)	14 (35.9%)	9 (23.1%)



Table B6: emerging technologies that are part of technology roadmaps in South Africa

	Number of Respondents	Percentage of Respondents (n=43)
Renewable Energy**	21	48.8
Big Data/ Internet of Things	16	37.2
Nanotechnology	11	25.6
Biotechnology	9	20.9
Environmental Technologies*	8	18.6
Robotics/ Automation	8	18.6
3D/ 4D Printing	6	14
Photonics	5	11.6
Aerostructures	3	7
4G and 5G FTTx	1	2.3
Satellite Technology	1	2.3
Mining and Processing Technology	1	2.3

* including Water and Sanitation | ** including Energy Storage



Table B7: selection criteria for emerging technologies that are part of technology roadmaps

	Future Value	Research Capacity	Engineering/ Manufacturing Capacity	Market Needs	Societal Needs	Alignment to Global Trends	Relevance to the Country
Aero Structures	2 (66.7%)	2 (66.7%)	2 (66.7%)	2 (66.7%)	1 (33.3%)	3 (100%)	1 (33.3%)
Big Data/ Internet of Things	13 (81.3%)	3 (18.8%)	2 (12.5%)	13 (81.3%)	5 (31.3%)	14 (87.5%)	3 (18.8%)
Biotechnology	6 (66.7%)	5 (55.6%)	3 (33.3%)	6 (66.7%)	5 (55.6%)	6 (66.7%)	4 (44.4%)
3D/ 4D Printing	3 (50%)	4 (66.7%)	4 (66.7%)	5 (83.3%)	3 (50%)	5 (83.3%)	1 (16.7%)
Environmental Technologies	5 (62.5%)	4 (50%)	1 (12.5%)	2 (25%)	4 (50%)	5 (62.5%)	6 (75%)
Nanotechnology	6 (54.5%)	6 (54.5%)	4 (36.4%)	8 (72.7%)	4 (36.4%)	8 (72.7%)	4 (36.4%)
Photonics	4 (80%)	3 (60%)	3 (60%)	4 (80%)	1 (20%)	5 (100%)	1 (20%)
Renewable Energy	11 (52.4%)	9 (42.9%)	7 (33.3%)	11 (52.4%)	9 (42.9%)	13 (61.9%)	16 (76.2%)
Robotics/ Automation	6 (75%)	3 (37.5%)	3 (37.5%)	6 (75%)	3 (37.5%)	5 (62.5%)	1 (12.5%)
4G and 5G FTTx	1 (100%)	-	-	1 (100%)	-	1 (100%)	-
Satellite Technology	1 (100%)	-	-	1 (100%)	-	-	-
Mining and Processing Technology	1 (100%)	-	-	-	-	-	-
All Technologies	28 (63.6%)	14 (31.8%)	10 (22.7)	24 (54.5%)	13 (29.5%)	31 (70.5%)	20 (45.5%)

Table B8: anticipated impact of emerging technologies that are part of technology roadmaps

	New Industry Creation	Improvement of Current Industry	New Products Development	Improvement of Existing Products	Increase in Exports	Improvement of Processes
Aero Structures	2 (66.7%)	2 (66.7%)	3 (100%)	1 (33.3%)	1 (33.3%)	1 (33.3%)
Big Data/ Internet of Things	6 (37.5%)	10 (62.5%)	13 (81.3%)	10 (62.5%)	2 (12.5%)	7 (43.8%)
Biotechnology	6 (66.7%)	5 (55.6%)	9 (100%)	6 (66.7%)	1 (11.1%)	3 (33.3%)
3D/ 4D Printing	6 (100%)	5 (83.3%)	6 (100%)	5 (83.3%)	1 (16.7%)	4 (66.7%)
Environmental Technologies	4 (50%)	4 (50%)	6 (75%)	5 (62.5%)	1 (12.5%)	3 (37.5%)
Nanotechnology	7 (63.6%)	6 (54.5%)	11 (100%)	7 (63.6%)	2 (18.2%)	6(54.5%)
Photonics	4 (80%)	4 (80%)	5 (100%)	3 (60%)	1 (20%)	1 (20%)
Renewable Energy	14 (66.7%)	12 (57.1%)	15 (71.4%)	10 (47.6%)	6 (28.6%)	7 (33.3%)
Robotics/ Automation	5 (62.5%)	7 (87.5%)	6 (75%)	6 (75%)	1 (12.5%)	2 (25%)
4G and 5G FTTx	-	1 (100%)	1 (100%)	1 (100%)	-	1 (100%)
Satellite Technology	-	-	-	-	-	1 (100%)
Mining and Processing Technology	1 (100%)	-	-	-	-	-
All Technologies	24 (54.5%)	26 (59.1%)	31 (70.5%)	23 (52.3%)	8 (18.2%)	17 (38.6%)



Framework for Technology Roadmapping in Developing Countries:

Table B9: stages of technology roadmapping practice in South Africa

	1st Generation TRM	2nd Generation TRM	3rd Generation TRM
Rank 1	10 (25%)	13 (32.5%)	17 (42.5%)
Rank 2	9 (22.5%)	22 (55%)	9 (22.5%)
Rank 3	21 (52.5%)	5 (12.5%)	14 (35%)

Table B10: relationship between main priorities for innovation programmes and technology roadmapping generation

	1st Generation TRM	2nd Generation TRM	3rd Generation TRM	All Roadmap Generations
Basic and/ or Applied Research	2 (11.8%)	7 (41.2%)	8 (47.0%)	18 (41.9%)
Technological Development	5 (17.9%)	9 (32.1%)	14 (50.0%)	32 (74.4%)
Product Development/ Manufacturing	3 (21.4%)	4 (28.6%)	7 (50.0%)	15 (34.9%)
Process Development	5 (38.5%)	4 (30.8%)	4 (30.8%)	16 (37.2%)
Service Offering	3 (30.0%)	3 (30.0%)	4 (40.0%)	11 (25.6%)
Market Development/ Entrepreneurship	4 (30.8%)	2 (15.4%)	7 (53.8%)	13 (30.2%)
Technology Localisation and Adaptation	4 (30.8%)	3 (23.1%)	6 (46.2%)	14 (32.6%)

Table B11: types of technology roadmapping organisations

	Number of Respondents	Percentage of Respondents (n=40)
Government	18	45
Science Council	18	45
State Owned Enterprises	15	37.5
Large Company	13	32.5
Industry Association	9	22.5
SME	8	20
International Organisation Outside of South Africa	8	20
International Organisation in South Africa	7	17.5
Not-for-Profit Organisation	5	12.5
Higher Education Institution	4	10

Table B12: targeted beneficiary industries for technology roadmaps

	Number of Respondents	Percentage of Respondents (n=40)
Manufacturing	21	52.5
Electricity, Gas and Water Supply	17	42.5
General Government	10	25
Agriculture, Forestry and Fishing	9	22.5
Transport, Storage and Communication	9	22.5
Mining and Quarrying	7	17.5
Community, Social and Personal Services	3	7.5
Personal and Household Goods	1	2.5
Financial Services	1	2.5

**Table B13: examples of technology roadmaps in South Africa**

Technology Roadmap	Access Location
Additive Manufacturing Roadmap of South Africa	Not Available
Cabinet approved carbon capture and storage roadmap	Not Available
Future Mobile Tech roadmap, Future of Work	Not Available
Future Mobile Technology Roadmap	Not Available
ICT in Agriculture Roadmap	Not Available
ICT RDI Roadmap	http://www.meraka.org.za/ictroadmap/sites/default/files/Roadmap%20-%20DEV12.pdf
IRENA's renewable energy roadmaps (REmap) studies	Not Available
SETRM	http://www.energy.gov.za/files/SETRM/setrm_energietechnology.html
Solar Thermal Roadmap of South Africa	http://www.soltrain.co.za/wp-content/uploads/2016/02/Solar-Thermal-Roadmap_South-Africa.pdf
South African Coal Roadmap	http://www.sacccs.org.za/About-Us/SA-CCS-Roadmap/
South African Solar Thermal Technology Roadmap which is part of a Regional S&T TRMs	Not Available
Water RDI Roadmap	http://www.wrc.org.za/Pages/KH_AdvancedSearch.aspx?k=2305&ww=1&

Table B14: time length of technology roadmaps by roadmapping organisation type

	Less than 5 Years	Between 5 and 10 Years	Between 10 and 15 Years	Between 15 and 20 Years	Between 20 and 25 Years	More than 25 Years
Government	1 (5.6%)	6 (33.3%)	7 (38.9%)	2 (11.1%)	1 (5.6%)	1 (5.6%)
State Owned Enterprise	1 (6.7%)	5 (33.3%)	5 (33.3%)	1 (6.7%)	2 (13.3%)	1 (6.7%)
Large Company	2 (15.4%)	6 (46.2%)	3 (23.1%)	1 (7.7%)	-	1 (7.7%)
SME	1 (12.5%)	2 (25%)	3 (37.5%)	-	1 (12.5%)	1 (12.5%)
NPO	-	2 (40%)	2 (40%)	-	-	1 (20%)
Industry Association	-	3 (33.3%)	3 (33.3%)	2 (22.2%)	-	1 (11.1%)
International Organisation in South Africa	-	-	5 (71.4)	1 (14.3%)	1 (14.3%)	-
International Organisation Outside of South Africa	1 (12.5%)	2 (25%)	3 (37.5%)	1 (12.5%)	-	1 (12.5%)
Science Council	1 (5.6%)	7 (38.9%)	6 (33.3%)	2 (11.1%)	1 (5.6%)	1 (5.6%)
Higher Education	-	2 (50%)	2 (50%)	-	-	-
All Roadmapping Organisations	6 (15.0%)	15 (37.5%)	12 (30%)	4 (10%)	2 (5%)	1 (2.5%)

**Table B15: time length of technology roadmaps per target industry**

	Less than 5 Years	Between 5 and 10 Years	Between 10 and 15 Years	Between 15 and 20 Years	Between 20 and 25 Years	More than 5 Years
Agriculture, Forestry and Fishing	-	3 (33.3%)	3 (33.3%)	2 (22.2%)	1 (11.1%)	-
Mining and Quarrying	-	2 (28.6%)	2 (28.6%)	2 (28.6%)	1 (14.3%)	-
Manufacturing	3 (14.3%)	11 (52.4%)	4 (19%)	2 (9.5%)	1 (4.8%)	-
Electricity, Gas and Water Supply	-	4 (23.5%)	8 (47.1%)	2 (11.8%)	2 (11.8%)	1 (5.9%)
Personal and Household Goods	1 (100%)	-	-	-	-	-
Transport, Storage and Communication	2 (22.2%)	4 (44.4%)	2 (22.2%)	1 (11.1%)	-	-
Financial Services	-	-	1 (100%)	-	-	-
Community, Social and Personal Services	1 (33.3%)	-	2 (66.7%)	-	-	-
General Government	2 (20%)	3 (30%)	5 (50%)	-	-	-
All Target Industries	6 (15.0%)	15 (37.5%)	12 (30%)	4 (10%)	2 (5%)	1 (2.5%)

Table B16: level of technology roadmaps integration per roadmapping organisation type

	TRM Integrated with other Internal Roadmaps			TRM Integrated with other External Plans		
	Yes	No	Not Sure	Yes	No	Not Sure
Government	13 (72.2%)	-	5 (27.8%)	16 (88.9%)	-	2 (11.1%)
State Owned Enterprise	11 (73.3%)	-	4 (26.7%)	13 (86.7%)	-	2 (13.3%)
Large Company	10 (76.9%)	2 (15.4%)	1 (7.7%)	10 (76.9%)	1 (7.7%)	2 (15.4%)
SME	6 (75%)	-	2 (25%)	7 (87.5%)	-	1 (12.5%)
NPO	5 (100%)	-	-	4 (80%)	-	1 (20%)
Industry Association	8 (88.9%)	-	1 (11.1%)	8 (88.9%)	-	1 (11.1%)
International Organisation in SA	5 (71.4%)	-	2 (28.6%)	5 (71.4%)	-	2 (28.6%)
International Organisation Outside of SA	5 (62.5%)	1 (12.5%)	2 (25%)	5 (62.5%)	2 (25%)	1 (12.5%)
Science Council	13 (72.2%)	1 (5.6%)	4 (22.2%)	15 (83.3%)	1 (5.6%)	2 (11.1%)
Higher Education	3 (75%)	-	1 (25%)	3 (75%)	-	1 (25%)
All Organisations	27 (67.5%)	3 (7.5%)	10 (25%)	30 (75%)	3 (7.5%)	7 (17.5%)

Table B17: level of technology roadmap integration per target industry

	TRM Integrated with other Internal Roadmaps			TRM Integrated with other External Plans		
	Yes	No	Not Sure	Yes	No	Not Sure
Agriculture, Forestry and Fishing	7 (77.8%)	-	2 (22.2%)	7 (77.8%)	-	2 (22.2%)
Mining and Quarrying	6 (85.7%)	-	1 (14.3%)	6 (85.7%)	-	1 (14.3%)
Manufacturing	17 (81%)	2 (9.5%)	2 (9.5%)	16 (76.2%)	3 (14.3%)	2 (9.5%)
Electricity, Gas and Water Supply	9 (52.9%)	-	8 (47.1%)	13 (76.5%)	-	4 (23.5%)
Personal and Household Goods	-	1 (100%)	-	-	-	1 (100%)
Transport, Storage and Communication	7 (77.8%)	-	2 (22.2%)	8 (88.9%)	-	1 (11.1%)
Financial Services	1 (100%)	-	-	1 (100%)	-	-
Community, Social and Personal Services	3 (100%)	-	-	3 (100%)	-	-
General Government	7 (70%)	-	3 (30%)	9 (90%)	-	1 (10%)
All Target Industries	27 (67.5%)	3 (7.5%)	10 (25%)	30 (75%)	3 (7.5%)	7 (17.5%)

**Table B18: technology roadmaps' planning period and their usage**

TRM Usage TRM Period	As Strategy/ Policy Development Tool	As Strategy/ Policy Implementation Tool
Less than 5 Years	2 (33.3%)	5 (83.3%)
Between 5 and 10 Years	10 (66.7%)	10 (66.7%)
Between 10 and 15 Years	7 (58.3%)	7 (58.3%)
Between 15 and 20 Years	4 (100%)	1 (25%)
Between 20 and 25 Years	2 (100%)	-
More than 25 Years	1 (100%)	1 (100%)
All Respondents	26 (65%)	24 (60%)

Table B19: structures put in place for development of technology roadmaps

	Number of Respondents	Percentage of Respondents (n=40)
Formation of a New Roadmapping Team with External Partners	27	67.5
Formation of a New Division/ Organisation Wide Roadmapping Team/ Committee	8	20.0
Normal Organisational Operating Team	7	17.5
Central Organisational Strategic Planning Team	7	17.5
Not Sure	1	2.5

Table B20: technology roadmapping structure per roadmapping organisation type

	Normal Organisational Operating Team	Central Organisational Strategic Planning Team	Formation of a New Division/ Organisation Wide Roadmapping Team/ Committee	Formation of a New Roadmapping Team with External Partners
Government	3 (16.7%)	2 (11.1%)	3 (16.7%)	16 (88.9%)
State Owned Enterprise	2 (13.3%)	1 (6.7%)	3 (20%)	13 (86.7%)
Large Company	2 (15.4%)	2 (15.4%)	4 (30.8%)	7 (53.8%)
SME	-	1 (12.5%)	-	7 (87.5%)
NPO	1 (20%)	-	-	4 (80%)
Industry Association	-	1 (11.1%)	1 (11.1%)	8 (88.9%)
International Organisation in South Africa	-	1 (14.3%)	1 (14.3%)	7 (100%)
International Organisation Outside of South Africa	-	2 (25%)	2 (25%)	6 (75%)
Science Council	1 (5.6%)	2 (11.1%)	2 (11.1%)	16 (88.9%)
Higher Education Institution	-	-	-	3 (75%)

Table B21 technology roadmapping structure per target industry

	Normal Organisational Operating Team	Central Organisational Strategic Planning Team	Formation of a New Division/ Organisation Wide Roadmapping Team/ Committee	Formation of a New Roadmapping Team with External Partners
Agriculture, Forestry and Fishing	2 (22.2%)	-	1 (11.1%)	9 (100%)
Mining and Quarrying	-	-	1 (14.3%)	6 (85.7%)
Manufacturing	2 (9.5%)	2 (9.5%)	3 (14.3%)	18 (85.7%)
Electricity, Gas and Water Supply	3 (17.6%)	1 (5.9%)	2 (11.8%)	15 (88.2%)
Personal and Household Goods	1 (100%)	-	-	-
Transport, Storage and Communication	3 (33.3%)	3 (33.3%)	1 (11.1%)	5 (55.6%)
Financial Services	1 (100%)	-	-	1 (100%)
Community, Social and Personal Services	-	-	-	3 (100%)
General Government	2 (20%)	3 (30%)	3 (30%)	6 (60%)

**Table B22: sponsor(s) for technology roadmap development process**

	Number of Respondents	Percentage of Respondents (n=39)
Organisational Internal Funding	19	48.7
Government	18	46.2
International organisation (s)	9	23.1
Local Stakeholders (including industry associations)	4	10.3

Table B23: criteria for selection of products and or technologies per type of sponsor

	Proven R&D Outputs	Technology Maturity Level	Existing Manufacturing Capacity	Market/ Stakeholders/ Societal Needs
Organisational Internal Funding	11 (57.9%)	14 (73.7%)	4 (21.1%)	12 (63.2%)
Local Stakeholders	1 (25%)	2 (50%)	1 (25%)	3 (75%)
Government	9 (50%)	13 (72.2%)	4 (22.2%)	15 (83.3%)
International Organisation (s)	3 (33.3%)	7 (77.8%)	2 (22.2%)	7 (77.8%)
All Sponsorship Types	20 (50%)	29 (72.5%)	8 (20%)	27 (67.5%)

Table B24: technology roadmapping consensus making process per type of sponsor

	Desktop Study	Forecasting Methods	Expert (s) Judgement	Workshop (s)	Vote by Key Stakeholders	Survey
Organisational Internal Funding	9 (47.4%)	4 (21.1%)	10 (52.6%)	15 (78.9%)	7 (36.8%)	-
Local Stakeholders	2 (50%)	1 (25%)	3 (75%)	4 (100%)	2 (50%)	-
Government	11 (66.1%)	4 (22.2%)	15 (83.3%)	16 (88.9%)	8 (44.4%)	1 (5.6%)
International Organisation (s)	5 (55.6%)	3 (33.3%)	9 (100%)	8 (88.9%)	2 (22.2%)	
All Sponsorship Types	22 (55%)	8 (20%)	26 (65%)	32 (80%)	13 (32.5%)	1 (2.5%)

Table B25: other tools that are incorporated during technology roadmapping process

	Number of Respondents	Percentage of Respondents (n=40)
Competitive Analysis	24	64.0
Capability Analysis	23	57.5
Scenario Planning	23	57.5
Lifecycle Analysis	21	52.5
Business Process Analysis	15	37.5
Portfolio Analysis	15	37.5
Ecosystem Analysis	11	27.5
Strategy Canvas	9	22.5
Delphi Technique	2	5

Table B26: TRM time horizon and tools used during technology roadmapping process

	Less than 5 Years	Between 5 and 10 Years	Between 10 and 15 Years	Between 15 and 20 Years	Between 20 and 25 Years	More than 25 Years
Business Process Analysis	3 (20%)	6 (40%)	5 (33.3%)	-	1 (6.7%)	-
Portfolio Analysis	2 (13.3%)	9 (60%)	3 (20%)	1 (6.7%)	-	-
Lifecycle Analysis	2 (9.5%)	6 (28.6%)	8 (38.1%)	2 (9.5%)	2 (9.5%)	1 (4.8%)
Competitive Analysis	3 (12.5%)	7 (29.2%)	9 (37.5%)	3 (12.5%)	1 (4.2%)	1 (4.2%)
Capability Analysis	2 (8.7%)	10 (43.5%)	10 (43.5%)	-	-	1 (4.3%)
Delphi Technique	-	-	2 (100%)	-	-	-
Workshops	4 (12.1%)	11 (33.3%)	12 (36.4%)	4 (12.1%)	1 (3%)	1 (3%)
Strategy Canvas	3 (33.3%)	1 (11.1%)	3 (33.3%)	2 (22.2%)	-	-
Ecosystem Analysis	1 (9.1%)	3 (27.3%)	4 (36.4%)	-	2 (18.2%)	1 (9.1%)
Scenario Planning	3 (13%)	7 (30.4%)	8 (34.8%)	3 (13%)	1 (4.3%)	1 (4.3%)
All Roadmapping Tools	6 (15%)	15 (37.5%)	12 (30%)	4 (10%)	2 (5%)	1 (2.5%)



Table B27: technology roadmap generation and tools used during technology roadmapping process

	1st Generation TRM	2nd Generation TRM	3rd Generation TRM
Business Process Analysis	5 (33.3%)	5 (33.3%)	5 (33.3%)
Portfolio Analysis	1 (6.7%)	7 (46.7%)	7 (46.7%)
Lifecycle Analysis	6 (28.6%)	5 (23.8%)	10 (47.6%)
Competitive Analysis	5 (20.8%)	8 (33.3%)	11 (45.8%)
Capability Analysis	5 (21.7%)	9 (39.1%)	9 (39.1%)
Delphi Technique	1 (50%)	-	1 (50%)
Workshops	8 (24.2%)	12 (36.4%)	13 (39.4%)
Strategy Canvas	3 (33.3%)	1 (11.1%)	5 (55.6%)
Ecosystem Analysis	3 (27.3%)	1 (9.1%)	7 (63.6%)
Scenario Analysis	6 (26.1%)	6 (26.1%)	11 (47.8%)
All Roadmapping Tools	10 (25%)	13 (32.5%)	17 (42.5%)

Table B28: continuation of technology roadmapping structure/ committee per roadmapping organisation type

	Yes	No	Not Sure
Government	7 (38.9%)	7 (38.9%)	4 (22.2%)
State Owned Enterprise	5 (33.3%)	5 (33.3%)	5 (33.3%)
Large Company	4 (30.8%)	4 (30.8%)	3 (23.1%)
SME	3 (37.5%)	2 (25%)	3 (37.5%)
NPO	2 (40%)	3 (60%)	-
Industry Association	3 (33.3%)	3 (33.3%)	3 (33.3%)
International Organisation in South Africa	3 (42.9%)	2 (28.6%)	2 (28.6%)
International Organisation Outside of South Africa	3 (37.5%)	2 (25%)	2 (25%)
Science Council	5 (27.8%)	9 (50%)	4 (22.2%)
Higher Education Institution	1 (25%)	1 (25%)	2 (50%)
All Organisation Types	15 (39.5%)	14 (36.8%)	9 (23.7%)

Table B29: continuation of technology roadmapping structure/ committee per type of sponsor

	Yes	No	Not Sure
Organisational Internal Funding	8 (42.1%)	3 (15.8%)	6 (31.6%)
Local Stakeholders	2 (50%)	2 (50%)	-
Government	6 (33.3%)	9 (50%)	3 (16.7%)
International organisation (s)	5 (55.6%)	3 (33.3%)	1 (11.1%)
All Roadmapping Sponsors	15 (39.5%)	14 (36.8%)	9 (23.7%)

Table B30: ongoing functions of technology roadmapping structure/ committee

	Number of Respondents	Percentage of Respondents (n=38)
Implementation of the Roadmap	16	42.1
Monitoring of the Roadmap	13	34.2
Update of the Roadmap	12	31.6

Table B31: utilisation of developed technology roadmaps

	Number of Respondents	Percentage of Respondents (n=38)
Roadmap Actions are Implemented Broadly Across the Organisation/ Industry/ Government	21	55.30%
Roadmap Actions are Implemented Narrowly (not integrated across organisation/ industry/ government)	10	26.30%
Once-off Exercise, Roadmap Actions not Implemented	7	18.20%

**Table B32: technology roadmaps utilisation per organisation type**

	Once-off Exercise, Roadmap Actions not Implemented	Roadmap Actions are Implemented Narrowly (not integrated across organisation/ industry/ government)	Roadmap Actions are Implemented Broadly Across the Organisation/ Industry/ Government
Government	4 (22.2%)	4 (22.2%)	10 (55.6%)
State Owned Enterprise	3 (20%)	3 (20%)	9 (60%)
Large Company	2 (15.4%)	3 (23.1%)	6 (46.2%)
SME	2 (25%)	2 (25%)	4 (50%)
NPO	-	2 (40%)	3 (60%)
Industry Association	2 (22.2%)	1 (11.1%)	6 (66.7%)
International Organisation in SA	1 (14.3%)	1 (14.3%)	5 (71.4%)
International Organisation Outside of SA	1 (12.5%)	2 (25%)	4 (50%)
Science Council	4 (22.2%)	4 (22.2%)	10 (55.6%)
Higher Education Institution	3 (75%)	1 (25%)	-
All Organisations	7 (18.2%)	10 (26.3%)	21 (55.3%)

Table B33: technology roadmaps utilisation per sponsor type

	Once-off Exercise, Roadmap Actions not Implemented	Roadmap Actions are Implemented Narrowly (not integrated across organisation/ industry/ government)	Roadmap Actions are Implemented Broadly Across the Organisation/ Industry/ Government
Organisational Internal Funding	4 (21.1%)	3 (15.8%)	10 (52.6%)
Local Stakeholders	-	-	4 (100%)
Government	3 (16.7%)	4 (22.2%)	11 (61.1%)
International organisation (s)	1 (11.1%)	3 (33.3%)	5 (55.6%)
All Roadmapping Sponsors	7 (18.2%)	10 (26.3%)	21 (55.3%)

Table B34: responsibility for monitoring of TRM success level per organisation type

	TRM Committee/ Team	Internal Structure (not involved with TRM development)	Peer Review Mechanism by External Stakeholder	Appointed Service Provider	TRM Sponsor	Not Sure/ Nobody
Government	8 (44.4%)	1 (5.6%)	5 (27.8%)	3 (16.7%)	6 (33.3%)	1 (5.6%)
State Owned Enterprise	7 (46.7%)	3 (20%)	1 (6.7%)	4 (26.7%)	7 (46.7%)	1 (6.7%)
Large Company	5 (38.5%)	3 (23.1%)	3 (23.1%)	1 (7.7%)	5 (38.5%)	1 (7.7%)
SME	4 (50%)	1 (12.5%)	2 (25%)	1 (12.5%)	3 (37.5%)	1 (12.5%)
NPO	2 (40%)	1 (20%)	2 (40%)	-	3 (60%)	1 (20%)
Industry Association	4 (44.4%)	2 (22.2%)	3 (33.3%)	1 (11.1%)	4 (44.4%)	2 (22.2%)
International Organisation in South Africa	3 (42.9%)	-	2 (28.6%)	2 (28.6%)	2 (28.6%)	1 (14.3%)
International Organisation Outside of South Africa	3 (37.5%)	1 (12.5%)	2 (25%)	-	4 (50%)	1 (12.5%)
Science Council	5 (27.8%)	1 (5.6%)	3 (16.7%)	3 (16.7%)	9 (50%)	3 (16.7%)
Higher Education Institution	1 (25%)	-	-	-	3 (75%)	1 (25%)
All Organisations	18 (47.4%)	4 (10.5%)	6 (15.8%)	5 (13.2%)	13 (34.2%)	6 (15.8%)



Table B35: responsibility for monitoring of TRM success level per type of sponsor

	TRM Committee/ Team	Internal Structure (not involved with TRM development)	Peer Review Mechanism by External Stakeholder	Appointed Service Provider	TRM Sponsor	Not Sure
Organisational Internal Funding	10 (52.6%)	2 (10.5%)	1 (5.3%)	3 (15.8%)	5 (26.3%)	3 (15.8%)
Local Stakeholders	1 (25%)	1 (25%)	1 (25%)	1 (25%)	-	1 (25%)
Government	7 (38.9%)	1 (5.6%)	4 (22.4%)	3 (16.7%)	7 (38.9%)	2 (11.1%)
International organisation (s)	5 (55.6%)	2 (22.2%)	1 (11.1%)	2 (22.2%)	3 (33.3%)	-
All Roadmapping Sponsors	18 (47.4%)	4 (10.5%)	6 (15.8%)	5 (13.2%)	13 (34.2%)	6 (15.8%)

Table B36: factors contributing to success of technology roadmaps

	Number of Respondents	Percentage of Respondents (n=37)
Sufficient Capacity to Implement the Roadmap	19	51.4
Executive Support	18	48.7
External Buy-in by Stakeholders	18	48.7
The Roadmap Address the Key Strategic Issues	18	48.7
The Roadmap is Kept Alive/ Updated	14	37.8
Internal Buy-in by Staff	10	27
Continued Existence of Roadmapping Team/ Committee	9	24.3
Political Will	1	2.7
Not Sure	1	2.7

Table B37: factors contributing to failure of technology roadmaps

	Number of Respondents	Percentage of Respondents (n=38)
Lack of Executive Support	18	47.4
The Roadmap is not Kept Alive/ Updated	16	42.1
The Roadmapping was a Once-off Process	13	34.2
The Roadmap is Unrealistic	10	26.3
Lack of Internal Buy-in by Staff	9	23.7
Insufficient/ Lack of Funding	4	10.5
Lack of Political Will/ Government Micro Management	3	7.9
Not Sure/ Not Yet There	2	5.4

Table B38: suggested measures to improve impact of technology roadmaps for developing countries

	Number of Respondents	Percentage of Respondents (n=28)
Strong Emphasis on Implementation	12	42.9
Involvement of Stakeholders	8	28.6
Securing of Sufficient Funding for Roadmap Implementation	5	17.9
Increasing of TRM Profile	5	17.9
Constant Review of Technology Roadmaps (e.g. after every 2 years) and Strong M&E	4	14.3
Leadership Involvement	4	14.3