Collaboration in South Africa's Forestry-Products Biorefinery Innovation System

Examining the Knowledge Network of Leverage Professionals

Nicola Pat Jenkin

Supervisor: Prof. Andre Kraak

A thesis submitted to the Wits School of Education, Faculty of Humanities, University of the Witwatersrand in fulfilment of the requirements for the degree of Doctor of Philosophy

Johannesburg, October 2020

Abstract

The aim of this study is to deploy and develop technological systems of innovation (TIS) (the dominant approach to explaining the functions of an eco-innovation system) to account for the current status of the forestry-products biorefinery innovation system in South Africa, and the role that the knowledge network and individuals within it play in expediating the uptake of biorefinery technologies in South Africa. TIS tends to not explicitly consider the role of the individual, as it predominantly refers to the actor or organisational level, a shortcoming this thesis addresses.

To this end, the thesis interrogates three sets of research questions: (a) how collaborative is South Africa's forestry-products biorefinery innovation system? (b) what are the dynamics of the knowledge network associated with South Africa's forestry-products biorefinery innovation system? and (c) who are the key leverage professionals in the forestry-products biorefinery innovation system?

This study shows that the South African forestry-products biorefinery innovation system is not as collaborative as it could be, as it tends to inadequately integrate civil society into the innovation process. It also indicates that the system is transitioning from a formative to a mature stage, with most current emphasis on research and development (R&D). The findings also illustrate that business and biorefinery academics play a central role in knowledge generation and diffusion, which suggests a potential knowledge bias towards the biorefinery applications in which they specialise or adopt. Another key defining characteristic of the associated knowledge network is that it is composed of several intra-networks that tend to operate in silos, as opposed to a cohesive singular network. From a knowledge perspective, managerial, techno-economic research, engineering and technical competencies dominate. This provides an indicator as to why most forestry-products biorefinery activity in the country is focused on R&D. Given that knowledge and learning are central to system of innovation discourse, this study found that no one mode of knowledge generation is preferred, with a balanced use of codified and tacit knowledge application proposed. At the level of the individual, this study developed the theoretical concept of a "leverage professional" – an individual who plays a significant role in leveraging change within the system. The study identified a number of barriers that inhibit leverage professional agency, notably: (a) a lack of financial and managerial support; (b) disconnected government policy; (c) changing strategic foci; (d) weak capacity and knowledge amongst colleagues; and (e) workforce exodus overseas or to other sectors, with particular reference to millennials.

The significance of this study is two-fold: First, it provides an approach to exploring a TIS, from the high-level structural functions, through the associated knowledge network, through to the level of the individual, with all connected through the theoretical lens of an innovation system. Second, it shines a light on the individuals within the innovation system and explores their agency and associated characteristics and behavioural preferences when operating within a network. This study therefore builds on current TIS discourse, and most significantly the role of the individual in increasing the degree and effectiveness of collaboration in the forestry-products biorefinery innovation system.

Keywords: Technological Innovation System; Forestry-products; Biorefineries; Knowledge networks; Knowledge generation; Leverage professionals; Change agents

Declaration

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

Nicola Pat Jenkin

October 2020

Publications and presentations emanating from this research

Jenkin, N. (2019, May 30-31). *The South African biorefinery innovation system: Role of leverage professionals as catalysts for change* [Paper presentation]. Trade and Industrial Policy Strategies (TIPS) Annual Forum 2019, Midrand, South Africa.

Jenkin, N. (2017, December 6-8). *Understanding the interface between South Africa's pulp and paper sector and skills required to adopt biorefinery technologies: A case study* [Poster presenation]. Researching Work and Labour (RWL10), Rhodes University, Grahamstown, South Africa.

Acknowledgements

This thesis was supervised by Prof. Andre Kraak of the Centre for Researching Education and Labour (REAL) at the University of Witwatersrand, Johannesburg; and co-supervised by Prof. Bruce Sithole, Director and Chief Scientist in the Biorefinery Industry Development Facility at the Council for Scientific and Industrial Research (CSIR), and Dr Presha Ramsarup, Director of REAL, University of Witwatersrand. I am incredibly grateful to all of them. Andre was particularly generous with his time, providing guidance on literature and research, reviewing my writing, and providing encouragement when I needed it. Through his National Research Foundation funds, Andre also enabled me to attend national and international events, without which my work would be less rich. Bruce's enthusiasm for the potential of biorefineries in South Africa is inspirational and I would not have pursued the topic of study without it. He also generously provided access to most of those interviewed and gave much appreciated insight into the technological components of biorefineries. As for Presha, I wish to acknowledge her theoretical guidance and the opportunities provided to link this study to our work on sustainability and occupations.

I wish to thank all 39 of the individuals I interviewed during this study. They are the cornerstone of this research and without their input this study would be vacuous. Thank you for sharing your stories and for giving me the time to dig deep.

To my family and friends: You have been a source of encouragement and support throughout. Thank you for your patience!

To Bruce Conradie and associates, I wish to thank you for undertaking the painstaking task of carefully editing my thesis.

Finally, I wish to express grateful thanks to the Fibre Packaging and Manufacturing Sector Education and Training Authority (FP&MSETA), and the Chemical Industries Education and Training Authority (CHIETA) for providing financial assistance towards this research.

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Abbreviations

The most referred to abbreviations:

CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DTI	Department of Trade and Industry
DUI	doing, using and interacting
DUT	Durban University of Technology
ICFR	Institute for Commercial Forestry Research
IDC	Industrial Development Corporation of South Africa
IP	intellectual property
NCPC	National Cleaner Production Centre of South Africa
NGO	non-government organisation
OECD	Organisation for Economic Cooperation and Development
PAMSA	Paper Manufacturers' Association of South Africa
R&D	research and development
RSB	Roundtable on Sustainable Biomaterials
SA	South Africa
SDCEA	South Durban Community Environmental Alliance
SME	small to medium enterprise
STI	science, technology and innovation
TIPS	Trade and Industrial Policy Strategies
TIS	technological innovation system
UKZN	University of KwaZulu-Natal
WEF	World Economic Forum
WWF-SA	World Wide Fund for Nature South Africa

Chapter 1: Introduction

This chapter introduces the thesis by setting the topic of focus and scope. It also provides the motivation for undertaking a technological innovation system (TIS) study and using the framework as a core theoretical lens for practical interpretation. Other avenues of exploration extend from the core. Of interest is the exploration of the theory and analysis to ascertain the collaborative dynamics of the current South African forestry-products biorefinery innovation system.

The theoretical thread running through the study is the centrality of knowledge and learning within the biorefinery innovation process and system. The TIS provided a suitable framework to assess the level of collaboration through the structure and functions of South Africa’s forestry-products biorefinery innovation system. This included some tools to interrogate the nature of the knowledge base and network. While the TIS framework provided an analytical framework to build on to interrogate the level of collaboration in terms of its structure, functions and knowledge base, it and systems of innovation framework’s in general do not adequately provide a mechanism for assessing the individuals within the system and their agency and ability to improve biorefinery uptake.

Therefore, the intention of this study was to build on TIS research and discourse by developing a more in-depth understanding: first, of the dynamics of the knowledge network, knowledge generation and diffusion within it; and second, to better understand the characteristics, knowledge, roles and behavioural preferences of core individuals as social capital. This includes understanding their absorptive capacity and agency to transition a current system focused on research and development (R&D) to one of increased uptake.

To respond to the study’s intention, I started from two main assumptions. The first being that improved adoption of biorefinery technologies and products in South Africa would require a more collaborative innovation system including actors and individuals from government, industry, academia and civil society. It should also have an effective knowledge network to allow adequate knowledge to be generated and transferred. The second assumption being that the effective functioning of the system, and increased adoption of biorefinery technologies, would rely on key leverage professionals. The term “leverage professionals” is a conceptual one developed in this study to describe individuals with agency. To investigate this, this study aimed to answer the following three questions:

Question 1: How collaborative is South Africa's forestry-products biorefinery innovation system, and can it enable the scaling up of biorefinery technologies?

Question 2: What are the dynamics of the knowledge network associated with South Africa's forestry-products biorefinery innovation system?

Question 3: Who are the key leverage professionals in the forestry-products biorefinery innovation system, and what specific traits, knowledge, capabilities and behavioural preferences do they exhibit?

1.1 Area of focus and scope

The focus of this study was on the South African forestry-products sector, including upstream activities within the value chain, notably sawmilling and pulp and paper manufacture. Forestry products include timber and logs, solid wood products (such as furniture and panels) and fibre products (such as paper and board) (Adams & Montgomery, 2013).

Included within the scope is the harvesting and production of products and associated woody biomass residue from invasive alien plants. Alien vegetation is a unique, large-scale problem in South Africa. As such, it has elicited much attention from the government in the form of eradication programmes to both mitigate the issue and create jobs.

The focus on sawmilling and pulp and paper mills is intentional as it is in the milling phases of the value chain that much waste and residue is generated. It is estimated that up to 50% of a tree is not used in the final product. This means that up to 50% goes to waste, is stockpiled, sent to landfill or used as a low-grade energy source (Mkhize et al., n.d.; Sithole, 2017a, 2017b; Stafford, 2017). Biorefineries mitigate this issue by using the waste and residues as a feedstock in the biorefining process to produce fossil-fuel alternatives. In addition, they contribute by adding an additional financial value stream to a stagnating industry and therefore potential job losses. It has been suggested that biorefinery processing has the potential to create ten jobs for every one ton of biomass processed (DAFF, 2012a; Stafford et al., 2019a; Sithole, 2020). From an environmental perspective, biorefineries offer an opportunity for the industry to mitigate its greenhouse gas emissions, and harness the embedded losses, such as water, effort, time and money spent on growing and harvesting trees that would have gone to waste. It is for this reason that biorefinery technology innovations and associated products were the focus of this study (Sithole, 2020).

With respect to the knowledge network and leverage professional elements of this study, the focus is on the importance of knowledge and learning within the South African forestry-products biorefinery innovation system. The study explored how knowledge is generated and exchanged within this network, with an emphasis on knowledge dynamics and relationships. The individuals who formed the central thread of analysis throughout the study were the leverage professionals identified as active participants of agency within the knowledge network.

1.2 Motivation and rationale

As a practising environmental scientist and researcher for the past 24 years, I have become aware of the significant negative impact industry has on our environment, society and economy. This is due to the dominant linear model of extraction, manufacture, use and disposal. While initiatives to reduce this impact have been on the increase since the publication of Rachel Carson's *Silent Spring* (1962), our efforts to optimise manufacturing practices are not achieving the desired results. Accordingly, there is a growing argument for mitigation efforts to go beyond incremental change, aiming instead for large-scale and society-wide transformation that results in effective and significant change (Few et al., 2017; Gillard et al., 2016). Compounding this is the expectation that climate change, which is already having a significant effect on the forestry sector and associated forestry-based industries, will continue to do so (Vulturius & Swartling, 2013). The recent wild forest fires experienced in Australia 2019-2020 are a case in point (Yeung, 2020; Yu et al., 2020). In addition, as market economies shift away from printed media and traditional regions of production, the South African pulp and paper sector is having to adapt, like its contemporaries in the northern hemisphere (SA Department of Trade and Industry, 2018; Fibre Packaging & Manufacturing Sector Education & Training Authority [FP&MSETA], 2014; Paper Manufacturers' Association of South Africa [PAMSA], 2015, 2016a). This means seeking opportunities in their value chains to optimise production, reduce environmental impact and diversify their product portfolios to add additional value, renew their businesses and maintain competitive advantage (Hellsmark et al., 2016). As such, biorefinery innovations become a potential opportunity for consideration. Therefore, access to, diffusion and use of knowledge in this area become imperative for maintaining competitive advantage

(Castells, 1996; Kraak, 2007; Lundvall & Borrás, 1997). However, the speed of uptake is critical. Hetemäki et al. (2015) warned that this shift to, or introduction of, new technologies needs to be progressive; it should undergo a process of “creative destruction”.[1]

This study argues that for effective innovation to be implemented it needs to be collaborative, more specifically it needs to include all actors in the forestry-products value chain, notably government, industry, academia and civil society. The recognition of these four actor groups is referred to as a quadruple helix framework, in which civil society is seen as an equitable partner in the innovation process (Campbell et al., 2015; Carayannis et al., 2017; Carayannis et al., 2012; Carayannis & Campbell, 2010). However, the current South African forestry-products innovation system operates predominantly through a dual partnership between industry and academia, which does not exemplify a truly collaborative or quadruple helix structure. It is on this premise that this research explored how collaborative TIS’ enable knowledge acquisition and diffusion. It also allowed the investigation of how leverage professionals in the system could enable the increased uptake of biorefinery innovations in the forestry-products sector.

While there has been research on the quadruple helix framework in the forestry sector (for example, Grundel & Dahlström, 2016; Karvonen et al., 2015) and systems of innovation discourse in developing economies (for example, Chaminade & Padilla-Pérez, 2017; Egbetokun et al., 2017; Malerba & Mani, 2009), there was little quadruple helix-focused research identified in South Africa. That which was identified included the work of Van Heyningen (2016) on how socio-cognitive institutions within innovation systems enable sustainability transitions in Austria and South Africa; and that by Botha et al. (2016) and Douglas (2019) which focused on the application of collaborative TIS’ in South Africa. While this literature proved invaluable, it did not focus on biorefineries, eco-innovations, knowledge networks or individuals in a TIS.

As highlighted previously, knowledge and learning play a significant and strategic role in all variants of innovation system theory. This is because it is through knowledge and learning that a nation, regional cluster or firm can innovate to ensure its competitive advantage and survival (Grant, 1996; Kraak, 2007; Tallman et al., 2004; Zheng et al., 2016). This view moves beyond the notion of economies of scale, which postulates that cheap labour and competitive pricing lead to competitive advantage (Gibbons et al., 1994; Kraak, 2007). However, technology and

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[1] The term creative destruction originated with Schumpeter and is explained on page 56.

performance are driven and achieved in the modern economy through interaction and the sharing of knowledge and learning (Castells, 1996; Gibbons et al., 1994; Kraak, 2007; Lundvall, 2006; Parveen et al., 2016).

What becomes important in the learning economy (Lundvall, 1996, 2006; Lundvall & Johnson, 2016) is the overriding value placed on knowledge and learning. The learning economy has attributes, such as firm capability and competency, absorptive capacity, knowledge expertise, knowledge dissemination and practical wisdom. Its resource-based view allows a reconfiguring of knowledge in which interaction generates knowledge and builds firm competence enabling a dynamic and competitive economy. Therefore, through knowledge and learning, a firm's competitive advantage can be maintained and growth sustained through the absorption of existing knowledge or the creation of new knowledge (Nonaka et al., 2014; Nonaka & Takeuchi, 1995).

Knowledge and learning are identified as central to the innovation process throughout system of innovation literature and discourse (Coenen et al., 2017; Cooke, 2001; Jensen et al., 2007; Lundvall, 2016a, 2016b; Lundvall et al., 2002; Lundvall & Lorenz, 2007; Nelson, 1993; Toivanen & Lima-Toivanen, 2009). However, it is only in the relatively recent works of Evers (2014), Lund University's Centre for Innovation, Research and Competence in the Learning Economy ([CIRCLE] 2017), and Mossberg et al. (2018) that the dynamics of knowledge networks associated with biorefinery innovation systems have been explored. Aside from Evers, much of this research was published during the course of this study (see Bauer et al., 2017, 2018). While incredibly useful as foundational, informative and contextual research, most system of innovation literature tends to focus on knowledge at the organisational or actor level (the exception being some examples in regional innovation system (RIS) literature [for example, Cooke, 2013]). In addition, methods of analysis to assess collaboration in an innovation social or knowledge are often quantitative or use social network analysis tools (for example, Bauer, 2018; Bauer et al., 2018; Brennecke & Rank, 2016; Evers, 2014). This method, while acknowledging linkages in a network, does not adequately provide the tools for assessing the flows and type of knowledge in the network. For this, knowledge network analysis is more appropriate yet, from what can be ascertained, seldom used within TIS analysis. Analysis of knowledge networks (sometimes also referred to as learning- or knowledge-action networks) has been used in sustainability disciplines (for example, Aboal et al., 2018; Klewitz, 2017; Muñoz-Erickson et al., 2017). It was used notably in an informative study on the identification of knowledge flows to develop a strategic plan for an eco-centre in Australia (Li et al., 2018).

Knowledge network research relevant to this study frequently incorporated innovation as a theme of focus, as opposed to studying innovation systems in the theoretical sense. For example, see the work of Brennecke and Rank (2016), Cowan (2004) and Perini (2009). In other cases, knowledge network research was commonly viewed as a mechanism for inter-firm or organisational knowledge exchange. However, this tended to focus at the actor-level (for example, Luna & Velasco, 2010; Mossberg et al., 2018; Pugh & Prusak, 2013; Sammarra & Biggiero, 2008).

An in-depth review of system of innovation literature suggested that much of it preferred a systemic analytical focus (with firms at the centre) rather than a focus on individuals. This was acknowledged by Cozzens (2010, p. 363), who noted: "the lack of the role of individual actors in innovation systems is one of the major flaws of the innovation systems approach." However, it should be noted that some regional innovation studies have explicitly identified the individual as innovator, and in the case of Cooke (2013) provided innovator biographies in their work. In the main however, the literature on the topic of individuals as agents of change tends to sit within business and management research disciplines (for example, Alexander et al., 2016; Ernst & Chrobot-Mason, 2011; Ku & Du, 2015). This was almost solely the case for research on what would make an effective team (also known as [aka] a network in an innovation system). The most theoretically robust literature in this area was on Belbin's team role taxonomy (see Flores-Parra et al., 2018; Gibson & Nesbit, 2006; Higgs, 1996; Mostert, 2015; Swailes & McIntyre-Batty, 2002). Most other frameworks for articulating roles within a group were situated within secondary and grey organisational literature. In the main, individuals are indirectly referred to in innovation system literature as "human capital" or the "human factor" (for example, see Coleman, 1988; Gorsline, 1996; Mphahlele & Scerri, 2016). There is a focus on human capabilities and skills (often limited to scientific, technical, engineering and research), and the "stock of skills owned by individuals" (see Becker, 1993; Mphahlele & Scerri, 2016, p. 229). The concept of human capital is widely adopted in South African National Innovation System (NIS) strategy and reports (for example, Mphahlele & Scerri, 2016; Organisation for Economic Cooperation and Development [OECD], 2007; Paul et al., 2012; Rashamuse, 2018). At a most basic level, individuals are acknowledged in these sources in a purely quantitative form, such as the number of jobs. An example of this is South Africa's Operation Phakisa Programme, which aims to make significant shifts in economic areas of productivity such as chemicals and waste (SA Department of Environmental Affairs, 2019). All innovation, activities and initiatives proposed under the programme reference the potential number of jobs created. There is little reference to the nature of these jobs, who the individuals will be, or how such initiatives will be implemented from a human resource perspective.

A few authors in system of innovation literature have explored the social dimension of the innovation system using a social capital lens. Examples include Chaminade and Vang (2008), in their work on the globalisation of knowledge production and regional innovation policy; Chaminade and Roberts (2002), who investigated social capital as a mechanism for connecting knowledge within and across firms; and Bonfim et al. (2018), who explored social capital in innovation and technology inter- and intra-organisational settings. While these, and other similar literature, tap into the social network and learning component of innovation, they mainly refer to the actor-level in a system. They provide little insight at the individual level. While this might be seen as a gap, the abovementioned work by Bonfim et al. (2018) and work by Nahapiet and Ghoshal (1998) on social and intellectual capital in the firm was appealing to this study. Both provided a useful framework for assessing the structural, relational and cognitive dimensions of a knowledge network (which constitutes social capital).

As alluded to earlier, the focus of most TIS research is at the contextual or actor (organisational) level. There is little reference to the individuals and roles they play as catalysts for change within the innovation system or process. It is only relatively recently that research has begun to explore this dimension within education and labour research, and education for sustainability in South Africa. Notable is the sectoral research undertaken by the Greenskills Programme on greening occupations (Jenkin et al., 2016; Jenkin & Mudombi, 2018; Ramsarup et al., 2018; Rosenberg et al., 2017; Ward et al., 2017a), and agency in a sustainability context (see Kraft, 2017; Lotz-Sisitka, 2011, 2018; Van der Heijden et al., 2012). While not linked to systems of innovation or knowledge network constructs, the principles of innovation and knowledge networks are acknowledged in this research. In fact, it is the greening of occupations work, in which I am involved, that influenced and informed the desire to undertake this study. This study, however, goes beyond the greening of occupations. It explores, in more depth, the nuanced characteristics and behavioural preferences of individuals who may enable a more collaborative, effective and sustainable transition. For this purpose, research grounded in business and organisational theory tends to be more appropriate. However, such research mainly focuses on the roles of individuals in inter- and intra-firm organisational teams and contexts, as opposed to their system level roles (for example, Du Chatenier et al., 2010; Gibson & Nesbit, 2006; Kirkman & Shapiro, 2001; Mostert, 2015; Sherstyuk et al., 2016).

1.2.1 Advancing technological innovation system discourse and addressing the gaps

This study aimed to address the gaps in TIS literature on biorefineries, knowledge networks, and leverage professionals, by building on and expanding research in this area. It therefore explored the TIS, and how knowledge generation, acquisition and diffusion played a role in the development and uptake of biorefinery technologies in South Africa forestry-products sector. More specifically, it explored the possibility that, to expedite uptake, a more collaborative innovation model is required. By this, I mean the model should explicitly encompass civil society's contribution, as well as the social capital and roles of individuals as agency within it.

Aside from building on and contributing to previously mentioned theory, the application of analytical frameworks also needed to be adapted for this study. Most notable were:

- *Enhanced collaboration within TIS* – for specific references to collaboration in South Africa, I drew on the work of South African scholars, Botha et al. (2016) and Douglas (2019), who explored inequality and poverty in TIS. In addition, research on how systems of innovation or innovation policy can respond to large-scale challenges (see for example Cozzens, 2010; Cozzens & Kaplinsky, 2009; Kuhlmann & Rip, 2014, 2018). The work of Campbell et al. (2015); Carayannis et al. (2017) and Carayannis and Campbell (2010) was referred to with respect to the inclusion of civil society in a quadruple helix model.
- *Knowledge network and social capital dynamics* – influenced by an adaptation of the work of Bonfim et al. (2018) and Nahapiet & Ghoshal (1998).
- *Knowledge generation and learning in a TIS* – foundational work on systems of innovation provided a strong framing and understanding of the significance of knowledge generation and learning in the innovation process (for example, Cooke, 2001; Jensen et al., 2007, 2008; Lundvall, 1992; Lundvall & Johnson, 2016; Lundvall & Lorenz, 2007). The literature also provided a distinction between types of knowledge, such as codified and tacit, and various categorisations within this.
- *Mechanisms for generating and acquiring knowledge in the knowledge network* were informed by the knowledge type categorisations devised by Nonaka and Takeuchi (1995), who interrogated knowledge exchange in Japanese firms. They suggested a classification of knowledge which distinguished codified (systemic and conceptual) and tacit (routine and experiential).

- *Types of knowledge held within the network.* No one framework or tool was available to determine the types of knowledge required to coordinate and implement an effective biorefinery innovation system. Consequently, various authors (notably Bouraoui et al., 2011; Culpepper, 2003; Lindberg & Teras, 2014; Luna & Velasco, 2010; Markides, 2005; Morris & Barnes, 2006) were drawn on to develop a set of knowledge-types required. This included market and entrepreneurial, technological, product, process/procedural/management, and organisational knowledge.
- *The role and behavioural preferences of leverage professionals* – Belbin's (2010, 2019) team role taxonomy, in conjunction with organisational management concepts, were heavily drawn on to ascertain the roles and behavioural preferences likely to elicit agency. Concepts such as brokers (see Burt, 2005; Castro, 2015; Chen et al., 2015), boundary spanners (see Aldrich & Herker, 1977; Lundberg, 2013; Safford et al., 2017; Tushman & Scanlan, 1981), tempered radicals (see Meyerson, 2001, 2004; Quinn & Meyerson, 2008; Sparks, 2005), and positive deviants (see Appelbaum et al., 2007; Markova & Folger, 2012; Seidman & McCauley, 2008) were identified. They were combined with Belbin's framework to develop a hybrid set of behavioural preferences and definitions to assess the level of representation of these role types within the current biorefinery innovation system.

Of paramount importance for this study was the linking of theories. Systems of innovation was used as a framing meta-theory, and other theories and frameworks were built on to fill gaps. Innovation system theory, with an explicit orientation towards the functionalist technological innovation systems framework, therefore provided the foundation, benchmark for critique and thread running throughout the theoretical and analytical chapters. This linking of the theory is explained further in Chapter 3.

As such, this study proposes new and informed components of biorefinery innovation system research. These were the issue of explicit civil society incorporation, knowledge generation and exchange, and an advanced understanding of the role of leverage professionals as change agents in the uptake of biorefinery technologies and products. The study also demonstrates the need to consider network relations that enable enhanced social learning and the role of individuals in TIS discourse, particularly when assessing the scalability of commercially viable biorefinery innovation implementation. Finally, it adds to the growing body of TIS literature set in a developing economy context.

1.3 Research questions and objectives

To investigate how collaborative the South African forestry-products biorefinery innovation system is, or could be, this study aimed to answer the following three questions:

Question 1: How collaborative is South Africa's forestry-products biorefinery innovation system, and can it enable the scaling up of biorefinery technologies?

Question 2: What are the dynamics of the knowledge network associated with South Africa's forestry-products biorefinery innovation system?

Question 3: Who are the key leverage professionals in the forestry-products biorefinery innovation system, and what specific traits, knowledge, capabilities and behavioural preferences do they exhibit?

To capture the complexity of the forestry-products biorefinery innovation system, its associated knowledge network and the leverage professionals within it, data were gathered and analysed from two main sources:

- *research reports and strategy documents* produced by academics, research institutions, government departments and civil society organisations that referenced the green economy, bioeconomy and biorefineries in South Africa; and
- *interview transcripts* produced from 40 interviews with 39[2] leverage professionals operating in, or linked to, the South African biorefinery innovation system. See Appendix B for a list of the leverage professionals interviewed. These transcripts provided a rich source of insight and data for analysis.

The methods of gathering and analysing the interview transcripts and literature to inform the level of collaboration and maturity of the biorefinery innovation system, knowledge dynamics and characteristics of the leverage professionals are covered in detail in Chapter 3.

[2] The mismatch between number of interviews held and interviewees is due to three individuals having been interviewed twice, and two interviews where two individuals attended the same interview.

1.4 Overview of the thesis structure

Chapter 1 presents an introduction to the study. Chapter 2 presents the contextual foundation for the study with an overview of the South African forestry-products sector, its environmental challenges and biorefineries as mitigation to these challenges. The research methods and structure used in the study are then described in Chapter 3. Thereafter, the theoretical underpinnings of systems of innovation, of knowledge production and diffusion, and knowledge networks, and of leverage professionals are covered in Chapters 4, 5 and 6 respectively. Chapter 7 analyses the South African forestry-products biorefinery innovation system's structure, functions and level of collaboration. Chapter 8 presents an analysis of the dynamics of the innovation system's knowledge network, and Chapter 9 analyses leverage professional characteristics, knowledge, roles and behavioural preferences. Finally, Chapter 10 outlines the main conclusions and identifies both limitations to the study and final reflections.

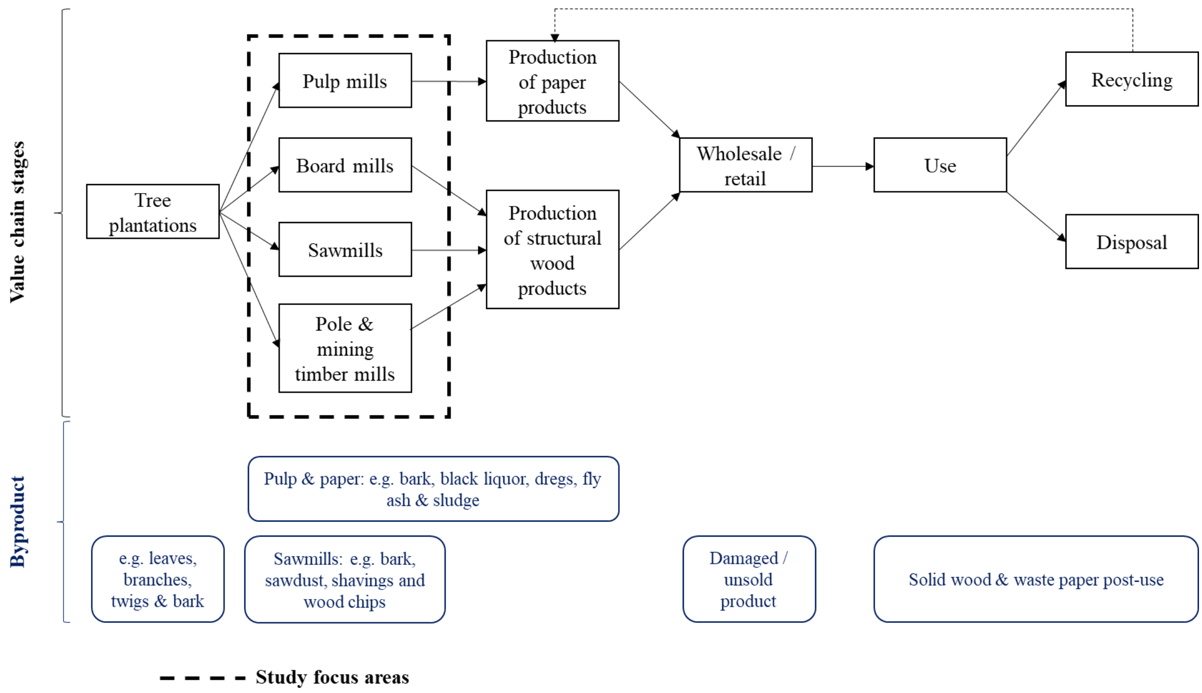
Chapter 2:
South Africa’s forestry-products sector: Biorefineries as an environmental response

The following chapter provides an overview of the South African forestry-products sector, the environmental challenges it faces, and how it aims to respond to these using biorefinery technologies. In terms of the forestry-products sector’s response to the need to mitigate its environmental impact, biorefineries are presented as one such response, and as the focus of this study. It should be noted that this chapter sets the context for the study, as opposed to the analysis of the sector’s TIS functions and characteristics, which is undertaken in Chapter 7.

Prior to providing a description of the sector and biorefineries as a response, a description of forestry products and their associated value chain is required. The concept of a “value chain” is best described as a series of connecting value-generating phases. These involve the transitioning of a product or products from raw material extraction or harvesting, to processing and manufacture, to consumption, and finally to disposal. It includes transport between the stages (Ingram et al., 2014; Kaplinsky & Morris, 2001; Sahoo et al., 2019; von Geibler et al., 2010). South Africa’s forestry-products value chain comprises the commercial growing of trees and the processing and manufacturing of forestry products (such as pulp and paper, timber and wood fuel) (Ledger, 2017; Nortje, 2018). As an indicator of magnitude, 57% of total plantations are allocated for pulpwood for paper-based products, and 37% for sawlogs (Forestry Economics Services, 2019, p. xii).

While the value chain for each forestry-products type is different, a typical forestry-products value chain is illustrated in Figure 1.

Figure 1: A typical forestry-products value chain[3]



The focus of this study is on mill operations (notably pulp and paper, and sawmilling) – indicated by the hashed box in Figure 1. The reason for this focus is that residues and byproducts from mills can provide significant feedstock for biorefineries (see Section 2.3.1 for further discussion). Sawmilling is the process of transforming sawn logs into lumber or timber for the construction sector. The products are also used in the manufacture of furniture, flooring, shelving and doors (SA Department of Water Affairs and Forestry, 2005; Ledger, 2017). Woodchips are also a significant product output from sawmills (Ledger, 2017; Sawmilling SA, 2014). Pulp and paper milling includes the processing of raw materials containing cellulose fibres sourced mainly from wood and recycled paper (PAMSA, 2016; Rosenfeld & Feng, 2011; World Bank, 1999). Wood used as a feedstock requires debarking and conversion to chips. The wood chips are processed into pulp to extract the fibres for use in the manufacture of paper, tissue and board (PAMSA, 2016; World Bank, 1999).

In 2018/2019, South Africa's forestry sector included 11 corporate forestry companies; approximately 21 100 small to medium timber growers (Nortje, 2018); approximately 170

[3] Developed by the author and adapted from: Godsmark & Oberholzer, 2019; Sahoo et al., 2019; Sustainable Forest Products, 2016; World Resources Institute & World Business Council for Sustainable Development (WRI & WBCSD), 2016.

sawmills[4] (M. Allpass, personal communication, November 19, 2019; Sawmilling SA, 2014), and 16 pulp and paper mills (Forestry Economics Services, 2019).

According to the latest market statistics, the South African commercial forestry-products sales value of timber products amounted to R27.87 billion (Forestry Economics Services, 2019, p. xx) – about 4.5% of South Africa’s manufacturing GDP (Statistics SA, 2019). Pulp and paper, and sawmilling dominated roundwood sales volumes (62% and 32% respectively) and value (58% and 26% respectively) (Forestry Economics Services, 2019, p. xx; Forestry SA, 2018; Godsmark & Oberholzer, 2019).

In terms of geographical location, most pulpwood production occurs in the provinces of KwaZulu-Natal and Mpumalanga and sawlogs in Mpumalanga, Eastern Cape and KwaZulu-Natal (Godsmark & Oberholzer, 2019). This activity distribution correlates with the main tree plantation areas, which tend to be situated in rural areas (Ledger, 2017). This in turn relates to the fact that the majority of the approximately 158 400 people employed (SA Government, 2018b) in the forestry sector are located in the rural areas of South Africa (SA Department of Trade and Industry, 2016). This indicates the importance of the sector in providing support to the estimated 650 000 people living in these areas (SA Department of Agriculture, Forestry and Fisheries, 2016). Of the total employed, an estimated 115 100 are employed directly, and 50 800 indirectly. The split by activity of employees is forestry (71 774), sawmilling (18 218), pulp and paper (43 247), and furniture production (26 400) (SA Department of Trade and Industry, 2016).

2.1 Pulp and paper: Apartheid as a catalyst for growth and dominance by a few

South Africa’s pulp and paper sector is steeped in a 100-year-old history. It has its origins in the 1920s and 1930s, from which it expanded into the industry it is today. Following World War I, the first paper mill was established near Johannesburg in the 1920s (Chamberlain et al., 2005; John, 2007; Timberwatch, 2007). This was in response to the South African government’s desire to encourage domestic wood-product manufacturing using locally grown wood.

[4] Estimated breakdown of sawmill types: Softwood (32 structural and approximately 90 non-structural mills), and hardwood (between 40 and 50 mills) (M. Allpass, personal communication, November 19, 2019).

During a period of growth in the 1920s and 1930s, further pulp and paper mills were established. The establishment of Sappi's first mill in 1936 (Timberwatch, 2007) became the springboard from which it grew into the leading international player it is today. Mondi, Sappi's main competitor, was established by Anglo-American in 1967 (Timberwatch, 2007).

The 1980s saw the pulp and paper industry focus its efforts on building new, modern processing mills adapted for South African conditions. These mills introduced technological advancements and significantly increased capacity. In the 1990s, the liberalisation of the market set a platform for the sector's expansion into international markets, mainly through the acquisition of mills in Europe and North America (John, 2007).

Today, the pulp and paper sector is a highly concentrated industry, dominated by Sappi and Mondi, now two of the world's largest multinational forestry-products companies. One of the main reasons cited for their dominance is the high capital required for pulp manufacture (SA Department of Trade and Industry, 2007). While other players, such as Corruseal, Kimberly-Clark, mPact, Neopak and the Twinsaver Group own large operations in the country, they are either not of South African origin or focus on one component of the value chain, such as packaging manufacture.

In addition, both Sappi and Mondi have global and vertically integrated supply chains, which further enhances their dominance in the South African market. They are the only producers of virgin fibre in the country and own most of the plantations from which they source wood-fibre (Chamberlain et al., 2005).

Wocke and Klein (2007) suggested in their study on emerging South African companies as global contenders that government protection enabled Sappi, for example, to benefit from and stimulate domestic manufacturing growth through mechanisms such as import controls and protection from competition. They also suggest that the government's afforestation incentivisation programme placed Sappi in a position of advantage. This enabled Sappi to build plants with capacity larger than local demand, thereby creating the necessity for an export market (Wocke & Klein, 2007). In addition, international sanctions applied to the country cemented the need for domestic manufacturing to play its role in the country's self-sufficiency.

In essence, the state created the Sappi and Mondi duopoly as a countrywide policy instrument. This incentivisation and protection is not dissimilar to that applied by the United States government and its federal financial and legislative incentives to support the renewable energy sector. This stimulated job creation, energy security and self-sufficiency (Aggarwal & Evenett, 2012).

Contemporary discourse would label Sappi and Mondi as "white monopoly capital" businesses, that is, large apartheid era private corporations that today continue to play a significant role in South Africa's economy.[5] These companies are said to have benefitted from having operated during apartheid, and continue to benefit by using this advantage as a platform for financial exploitation, dominance and expansion (Van der Walt, 2015). Therefore, it is argued by some that economic, class and racial inequalities that existed during apartheid continue to exist and make it difficult for black-owned entities to compete fairly (Zeus, 2019). This can limit the potential for radical economic transformation (Mutize & Gossel, 2017). This argument aside, what cannot be neglected is the scale of Mondi and Sappi's operations, and the implications their duopoly has for South Africa's pulp and paper market. For example, the implications of their vertically integrated operations for the sector can result in power imbalances between companies operating in the sector. It can also lead to unequal access to raw materials or market opportunities, ownership of assets, ability to employ adequately skilled individuals and a concentration of technical authority and knowledge (SA Department of Agriculture, Forestry and Fisheries, 2012; Fedderke & Simbanegavi, 2008; Roberts, 2006). This level of concentration reinforced the exclusivity of business under the apartheid regime (Chabane et al., 2006), with vertical mergers facilitating upstream collusion (Mncube et al., 2012).

In addition, with government support, a platform was created in the 1980s for Sappi and Mondi's global expansion. As such, today Sappi is one of the world's largest producers of coated wood-free paper (Sappi, 2019) and largest producer of dissolving wood pulp (Sappi, 2020). By moving beyond South Africa's boundaries, businesses such as Mondi and Sappi have increased their operational and financial footprint. They have remained competitive globally by reaping the financial rewards of owning operations in beneficial market supply or demand locations. To maintain their positions as global players and South African marketplace leaders, they reduced costs through mill closures (Industrial Development Corporation, 2014; Sappi,

[5] However some, such as Aboobaker (2019, p. 515), Mutize and Gossel (2017) and Van der Walt (2015) suggest the use of the term "white monopoly capital" presents a cover for more pertinent contemporary political concerns, such as government incompetence, poor service delivery and corruption. They suggest, therefore, that such terminology is harmful to South African discourse and the desire to transform.

2014) and reduced their product portfolios (Allix, 2016; Aykut & Goldstein, 2006; Mondi, 2020; PAMSA, 2016).

In spite of these growth and market adaptation interventions, the realities of global competition and changing trade dynamics pose significant challenges, such as market fluctuations, currency volatility and the downgrading of credit ratings (Campbell & Muller, 2016; Mondi, 2016b; PAMSA, 2017). These challenges are exacerbated by increasing input costs, an unstable energy supply and declining product prices and demand (Allix, 2016; PAMSA, 2017). However, the industry continues to focus its efforts on the export market, seeing this as one of its strengths (PAMSA, 2017). While the sector has been affected by China's declining growth rate, it is still seen as a major export partner (Donnelly, 2016; PAMSA, 2017; SA Market Insights, 2018). In addition, the sector is strengthened by South Africa becoming the global leader, through Sappi, in the production of dissolved wood pulp (DWP) (Kilian, 2018; Sappi, 2018b; Van Velze & Wagner, 2019). These economic developments illustrate the sector's response to the call by government and the private sector to re-establish manufacturing as the primary driver to recover the country's economy (SA Department of Trade and Industry, 2007; TAPPSA, 2016).

2.2 Sawmills: From natural forest resources to multiple scales of operation

The history of sawmilling in South Africa dates back further than that of pulp and paper manufacture. Its origins are in the use of wood sourced from indigenous forests in the 16th and 17th centuries for construction, shipbuilding and furniture (Mahlangu & Mubangizi, 2015). In the mid-1800s, the first commercial sawmills were established in Knysna, Western Cape province to meet the demands of an expanding colonial population and a merchant navy requiring ships. This made Knysna the centre of South Africa's sawmilling industry in the 19th-century (Caveney, 2015; SA Department of Water Affairs, 2005; Sawmilling SA, 2014; Stehle, 2013).

With the increasing demand for timber, private investors were attracted to the lucrative possibilities of producing timber (Mahlangu & Mubangizi, 2015). As such, one of the first major private companies, York Timbers, was established in 1916 (York Timbers, 2019). It is now one of South Africa's leading solid wood processors, having listed on the Johannesburg Stock Exchange (JSE) as early as 1946 (York Timbers, 2019).

The 1930s saw the first tree plantations established by Dr Hans Merensky in Tzaneen in what is now the Limpopo Province. He went on to become an integral figure in the forestry-products landscape, as both businessman and philanthropist (Ham et al., 2018). Today Hans Merensky Holdings (registered in 1949) is, along with York Timbers, a leading supplier of lumber and sawlogs to local, African and international markets (Merensky, 2019). The thirties also saw the commissioning of the first government-owned sawmills and plantations. It was around these mills that smaller private sawmills began to operate (SA Department of Water Affairs, 2005; Sawmilling SA, 2014). These smaller operators played (and continue to) a beneficial role in taking smaller wood and other off-cuts not of interest to the larger contractors (SA Department of Water Affairs, 2005).

In the interceding years, and up to the 1980s, both York Timbers and Merensky cemented their prominence in the sector. They did this by expanding their timber interests through vertically integrated operations (Merensky, 2019; York Timbers, 2019). The 1980s witnessed a shift from government support and ownership to the commercialisation of state-owned plantations (SA Department of Water Affairs and Forestry, 2006; Sawmilling SA, 2014). In the early 1990s, two new major players emerged on the market – Tekwani and the South African Forestry Company Limited (SAFCOL). Tekwani is a vertically integrated sawmilling company which started out in the Eastern Cape with a single sawmill and is now a large 30% black-owned business (Tekwani, 2019). SAFCOL is a state-owned entity operated by the Department of Public Enterprises (DPE). Their operations include timber harvesting and processing for the domestic and international markets (SAFCOL, 2019). While these large players existed in the 1990s, the sawmill landscape was characterised by mainly small-scale mills. However, they only produced about 10% of softwood sawlog output, with the ten largest operators producing most of the output (Heyl et al., 2000). As with the pulp and paper sector, larger players in the sawmilling industry prohibited the expansion of major investment (Heyl et al., 2000). However, as opposed to limiting the establishment of smaller players (as was the case in pulp and paper), Heyl et al. (2000) proposed that this restriction catalysed the growth of smaller sawmills. They suggested this was because smaller mills are more flexible and can accommodate market fluctuations.

Market challenges, which continue to exist today, began to surface in the early 2000s. The most significant of which was the demand for forestry-products' outstripping supply. This was predominantly attributed to the concentration and privatisation of plantations, state restructuring and decreasing water resources (Crickmay & Associates, 2004; Dineo, 2019; SA

Department of Water Affairs, 2005; FP&MSETA, 2014; Goko, 2017). These restrictions particularly impacted the smaller sawmillers and the awarding of contracts to access timber (Dineo, 2019; SA Department of Water Affairs, 2005). This timber shortage continued as a major challenge into 2017 (Goko, 2017; Mondi, 2016; Oliveira, 2017; Sappi, 2015), and affected both the sawmilling and pulp and paper sectors, as having a secure supply is critical for survival.

An additional challenge facing the sawmilling sector is the stability of the construction sector – a major customer (Ledger, 2017; Sawmilling SA, 2014). Should the construction sector go into decline, as it did in 2018, this impacts sawmilling output. However, with a growing middle class, the demand for state and private housing is predicted to significantly increase timber demand (Njobeni, 2019). This growth could be enhanced if South Africa adopted a more favourable response to wooden buildings, as is the case in many Scandinavian countries (Bailey & Buckingham, 2017; Manninen, 2014; Mosaka, 2018; Ramage et al., 2017).

2.3 Environmental impacts associated with forestry-products manufacture

Aside from the South African forestry-products sector contributing significantly to the country's economic profile (12% to manufacturing GDP [Ledger, 2017; Sithole, 2017b]), it also impacts the environment through its high usage of energy and water, air and water emissions, byproduct and waste generation.

Environmental impacts associated with energy consumption in the forestry-products sector are associated with, for example, transport and machinery fuel usage (Bosner et al., 2012), and the generation of heat during the sawmilling and manufacturing process (SA Department of Energy [DoE], 2019; Loeffler et al., 2016; Taylor & Bergman, 2019). As such, the manufacture of pulp and paper is the greatest user of energy in the forestry-products value chain (Gopalakrishnan & Anderson, 2005). Associated with this energy use are air emissions such as carbon dioxide (which is a major contributor to climate change) (Allen et al., 2018; Bosner et al., 2012) and volatile organic compounds from boilers and control equipment (Western Cape Government Department of Environmental Affairs and Development Planning [DEA&DP], n.d.; International Finance Corporation & World Bank, 2017).

The pulp and paper sector is particularly water-intensive, with water used for washing and production processes, cooling and energy production (Mondi, 2012). Associated with this water use is wastewater, which is commonly sent to treatment plants and subsequently discharged into rivers or the sea. Another factor associated with water consumption is a reduction in access to water supply due to the recent droughts in the country. For example, Sappi (2015) noted the need to reduce one of their mill's outputs because of reduced water supply. Given that approximately 80% of treated water is disposed into rivers or seas (Mondi, 2012; Sappi, 2015), poor treatment and pollution can have a significant impact, especially on water quality, and wetland, river and ocean ecosystems. In their study, *The contribution, costs and development opportunities of the forestry, timber, pulp and paper industries in South Africa*, Chamberlain et al. (2005) suggested that almost 70% of the sector's environmental impact was attributable to effluent impact on water quality and air emissions. Water impacts were estimated to cost the sector R206 million per annum (Chamberlain et al. 2005).

Waste as byproducts occurs across the forestry-products value chain. During harvesting, it is in the form of leaves, branches, twigs and bark. Sawmilling and processing lumber produces bark, sawdust, shavings and wood chips (including reprocessing). The manufacture of pulp and paper generates bark, black liquor, dregs, fly ash and sludge. At the post-use stage, solid wood waste and wastepaper are generated (Bosner et al., 2012; Sahoo et al., 2019; Sithole, 2017b; Stafford et al., 2019). This waste is the result of a highly inefficient tree utilisation system, with an estimated 47% yield; that suggests that more than 50% of a tree is wasted (Oliveira, 2017; Sithole, 2017b; Stafford et al., 2019). Biorefinery technologies provide a solution to this high level of waste and poor utilisation. They can improve resource efficiency, reduce disposal of waste to landfill costs, provide an opportunity for the sector to add value by diversifying its product portfolio (SA Department of Science and Technology, 2018d), and create jobs in doing so (Sithole, 2020).

In response to the environmental impacts associated with the sector, the South African forestry-products industry began to implement initiatives to mitigate these. This was particularly the case for businesses situated within global value chains. The recycling of paper is a good example of this, and an activity at which South Africa excels. The Paper Manufacturers Association of South Africa (PAMSA) suggests the country recovers 72% of its paper for recycling (Reintjes, 2019).

From a water perspective, all major South African pulp and paper manufacturers acknowledge that water is a critical and scarce resource. Consequently, it is one of their main assets and therefore its scarcity is the greatest risk to future operations (Corcoran, 2015; University of

Cambridge, 2017). Because of this, many have invested in projects to reduce water consumption through more efficient practices at their mills. For example, Mondi undertook a fundamental move to switch most of its water from potable to cleaned wastewater (Global Africa Network, 2018; Mondi, 2014, 2015).

2.3.1 Biorefineries as an environmental response

Mkhize et al., (n.d.) suggested that yield rates of 45% to 55% of tree usage have led to the generation of an estimated 8.3 million tonnes of biomass byproduct. It has even been reported that only 26% of a tree is extracted at some sawmills (Sithole, 2017a; J-P van der Merwe, Interview 22, September 25, 2018). While some of this byproduct is chipped (J-P van der Merwe, Interview 22, September 25, 2018) or used to generate energy in mills (Sawmilling SA, 2017; Stafford et al., 2019), the unused quantities are significant enough to warrant the identification of alternate value-add opportunities. This is particularly important because of the growing interest in utilising raw materials better in South Africa (C Smit, Interview 8, September 4, 2018), and by doing so, creating jobs (Sithole, 2020).

Biorefineries offer one such solution – through the beneficiation of sawmill and pulp and paper biomass waste (Phillips, 2014; Sithole, 2017b; Stafford et al., 2019). In a developing economy, such as South Africa, forestry biomass-based biorefineries present opportunities for small to medium enterprises to enter the market. This would create jobs (particularly in rural areas), contributing to local economies and the country’s transition towards a green economy (Council for Scientific and Industrial Research [CSIR], 2018; Fetola Foundation, 2019a; Manavhela, 2017; Sithole, 2020; Ungerer et al., 2017).

While a number of definitions exist, biorefining is the process of extracting, for example, carbohydrates and proteins from biomass, such as wood, corn and sugarcane. These are then converted or upgraded into biobased products, such as biofuels,[6] chemicals, energy and heat,

[6] Biofuels result from converting biomass into fuels for transportation. Types of biofuel include ethanol, biodiesel, methanol (wood alcohol) and reformulated gasoline components (Renewable Energy World, 2019).

nanocrystalline cellulose[7] and xylitol[8] (Berntsson et al., 2011; Görgens et al., 2015; Jungmeier et al., 2007; Phillips, 2014).

Berntsson et al. (2011) suggested the term “biorefinery” first appeared in the 1990s as a response to the industry’s increasing awareness that it needed to improve its resource efficiency from a cost and environmental perspective. The industry also needed to diversify its product portfolio to identify higher-value products. More recently, biorefineries are seen as an integral solution for countries committed to transitioning towards a circular bioeconomy, that is, in moving away from a fossil-fuel-based economy, as is the case in Sweden and Finland (Bauer et al., 2017; de Jong & Jungmeier, 2015; Giurca, 2017; Grundel, 2017; Hansen & Coenen, 2015; Van Eijck & Romign, 2009; WBCSD, 2019). This economic context is noted as being specific to a European definition. In the United States, such an economy is often characterised by its use of and reference to bio-technologies within a production system (Grundel, 2017). In both instances, Grundel (2017) suggested biotechnology innovations are introduced to strengthen a sectoral or regional economic market. He also claimed that a bioeconomy cannot exist without innovation. Biorefinery innovations are therefore a key technology within the broader category of bio- or eco-innovations.

A number of biorefinery systems exist. These are classified according to four features: (a) platform (such as sugars and proteins); (b) product group (bioenergy and associated products); (c) feedstock (crops and biomass residue); and (d) conversion process (biochemical, thermochemical, chemical and mechanical) (de Jong & Jungmeier, 2015; Ungerer et al., 2017). Feedstock is often categorised as “generations”: First-generation feedstock is crop-based, and second-generation feedstock is biomass residue or waste (King, 2010; Rashamuse, 2018; Ungerer et al., 2017).

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[7] Nanocrystalline cellulose is produced by acid hydrolysis to obtain cellulose fibres. Due to their size, nanocrystalline cellulose are durable, flexible and very strong. When combined with composite materials, they can be used in a variety of applications, such as chemicals, food, pharmaceuticals and biomedical applications (Bhat et al., 2017; Dalli et al., 2018).

[8] Xylitol can be obtained from the hemicellulose fraction of biomass, and is a natural [debated] alternative sweetener, having many food and pharmaceutical applications (Dávila et al., 2016).

2.3.2 Use of alien vegetation as feedstock

The use of invasive alien vegetation as a feedstock for biorefineries is also considered in this study. The reasons are twofold: First, the Department of Environment Affairs (DEA)[9] supports a large-scale alien clearing programme to provide employment through eradicating and harvesting alien vegetation (SA Department of Environmental Affairs, 2019a; Parliamentary Monitoring Group, 2015). Second, alien vegetation is a woody biomass and therefore has similarities to timber plantation and sawmill biomass. It is also often processed at sawmills, thereby generating residues, such as sawdust which can be used as feedstock for biorefineries (Jenkin & Mudombi, 2018; Stafford, 2017).

2.4 Conclusion

This chapter suggests that the South African forestry-products sector has adapted to a number of external factors: First, shifting market economies, a move away from printed media or a downturn in construction; secondly, fluctuations in feedstock availability; and thirdly, societal and political pressures to contribute to rural livelihoods and reduce its environmental burden. This means the sector has sought opportunities within its own value chains to optimise production, improve yields, identify added-value opportunities through product diversification and create jobs by doing so. Biorefineries can provide this opportunity. However, the speed of uptake is critical. Hetemäki et al. (2015) argued that this shift and introduction of new technologies needs to be progressive; it should undergo a process of creative destruction. For the purposes of this study, this means significant and disruptive change to the domination of fossil-fuel use and replacing this with biofuels and alternatives. This will lead to an increased demand for biorefineries. The effective adoption of biorefinery innovations and products relies, amongst other dimensions, on collaboration in the system. This may be in the form of generating new ideas through research and implementation of strategies to make the system work. It can also include the marketing, sale and use of new biorefinery products (Watkins et al., 2010). It is on this premise that this study is focused, with the characteristics of South Africa's biorefinery innovation system further explored in Chapter 7, thereby building on this scene-setting chapter.

[9] The DEA was renamed the Department of Environment, Forestry and Fisheries (DEFF) in June 2019, incorporating the forestry and fisheries functions from the previous Department of Agriculture, Forestry and Fisheries (DAFF) (SA Department of Environment, Forestry and Fisheries, 2020).

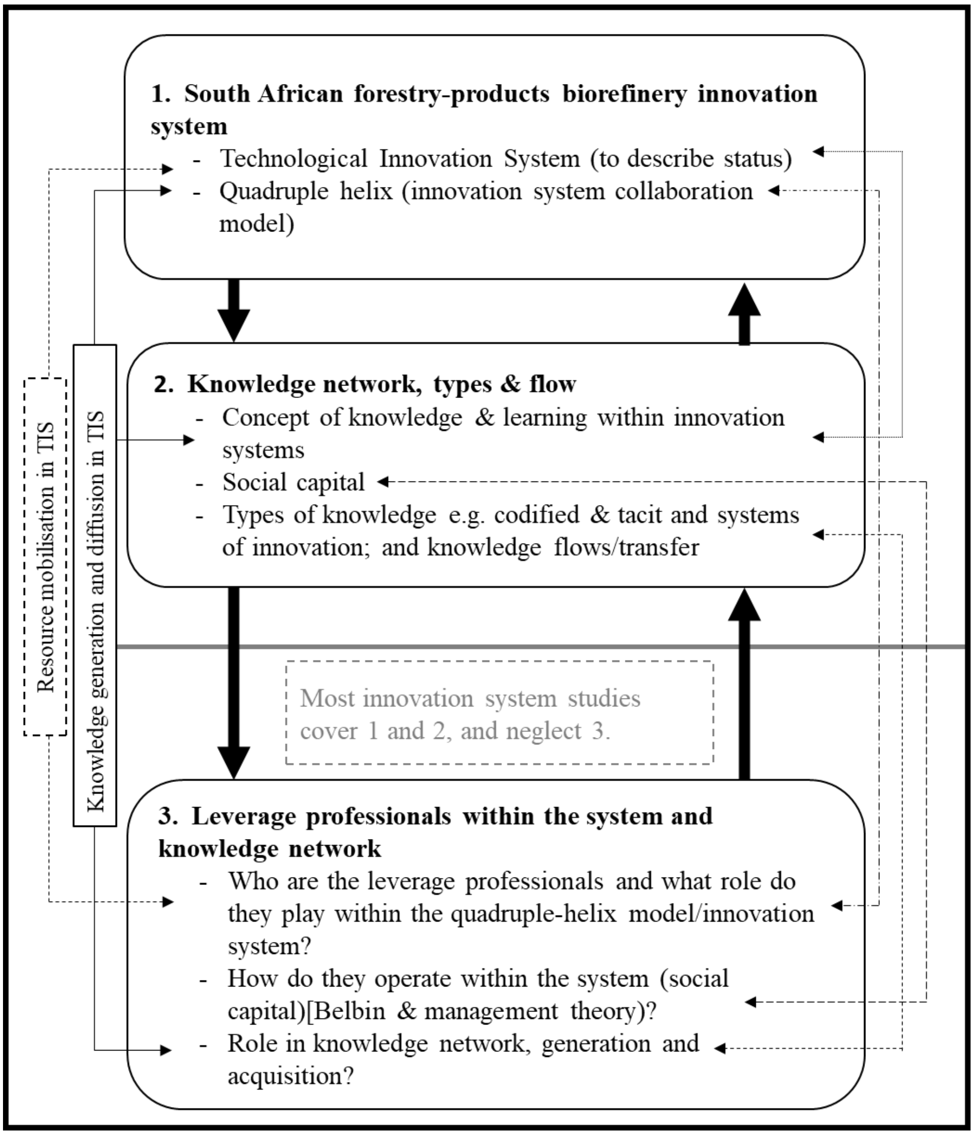
Chapter 3:
Research method and structure

This study argues that, for a forestry-products biorefinery innovation system to be implemented at scale in South Africa, it needs to be more collaborative than it currently is. In this regard, collaboration is interpreted as incorporating all actors in its value chain – government, industry, academia and civil society (referred to as the "quadruple helix" framework). As such, the role of leverage professionals as catalytic change agents in the TIS are investigated. This includes how they operate in the associated knowledge network, and how they exchange and acquire knowledge.

Given the study's intentions, different theoretical frameworks and therefore methodologies were required to interrogate the three core dimensions of the study: the forestry-products biorefinery innovation system, the associated knowledge network, and the leverage professionals operating in the system. The reason for this approach was that most variants systems of innovation research focus on a system's context and actors, with little reference, aside from some RIS literature, to the individuals who operate within it.

While each dimension is dealt with separately theoretically and analytically in the study, they are not treated in silos, but have broader systems of innovation constructs anchoring all components. Figure 2 illustrates this linkage which informed the approach structure adopted for this study.

Figure 2: Linking the theory to inform the methodological approach and structure[10]



3.1 Conceptual framework

The rationale for using systems of innovation as the overarching mega-perspective, with an orientation towards TIS, as the thread through this study is that biorefineries are a technological solution, and knowledge and learning are central to innovation system discourse. Given this, the TIS approach was identified as the most appropriate innovation system framework[11] to characterise and describe South Africa's forestry-products biorefinery innovation system and the level of collaboration within it. To validate the adoption of the TIS approach, it is noted that

[10] Developed by the author.

[11] Others being national, regional and sectoral innovation systems.

most TIS literature focuses on bio- and eco-innovations or sustainable technological change (see for example Bauer et al., 2017; Bößner et al., 2019; Hekkert et al., 2007; Hu, 2017; Jacobsson & Bergek, 2011; Planko et al., 2017; Van Heyningen, 2016; Walz et al., 2016).

This study recognises knowledge and learning as core components of systems of innovation and as key to "innovativeness" (Grønning & Fosstenløkken, 2015, p. 1), competitive advantage (Castells, 1996; Grant, 1996; Kraak, 2007; Tallman et al., 2004; Zheng et al., 2016) and survival (Gibbons et al., 1994; Lundvall, 2006). However, while NIS and TIS scholars may emphasise 'their' theory provides practical guides for policymakers and analysists, for the purpose of this study they did not provide the level of detail required to investigate in-depth how knowledge is generated, acquired and diffused within a knowledge network; and secondly, how to characterise and understand the types of knowledge generated and held within the network.

Given this, I explored organisational literature on the composition of knowledge networks and how people ("social capital" [see Burt, 2001, 2005]) are connected within these networks. This literature assisted my framing and understanding of how each leverage professional is positioned in the social capital structure, and how they generate and diffuse knowledge.

As this study intended to move beyond typical TIS and knowledge network studies by including leverage professionals, organisational literature was drawn on to provide this analysis. The reason for "dropping down a level" was that it has been suggested that it is at the level of the individual that change is either hindered or enabled (Du Chatenier et al., 2010; Lotz-Sisitka, 2018). Du Chatenier et al. (2010, p. 271) suggest in their work on professional competencies in open innovation teams that "individuals play a crucial role in collaborative knowledge creation processes." This was further acknowledged by Lotz-Sisitka (2018) in her work on change agency and green economy transitions. She recognised that "champions" or "pioneers" are significant influencers for driving successful sustainability programmes (ibid., p. 63).

While the use of mixed qualitative theories and approaches may appear less controlled, I believe that situating the study under the umbrella of systems of innovation (see Figure 2) has aided the cohesiveness of the study. In addition, established methods of analysis for TIS, knowledge networks, knowledge types, and leverage professionals were used in this study to limit the random application of methods.

The following sections provide a detailed description of the selection and application of the methodologies used. They also describe, where developed, novel or iterative methods adopted to address a gap in the literature.

3.2 Methodological design

This section comprises two parts. The first section describes the process for setting out the context of the South African forestry-products sector, and the literature analysis approach for TIS, knowledge networks and generation, and leverage professionals. The second section focuses on the methodological design and analytical application used to assess South Africa's forestry-products biorefinery innovation system, its knowledge network, and the leverage professionals operating within it.

3.2.1 Setting the contextual and theoretical foundations

In the first part of this study, Chapter 2 provided a contextual setting for the South African forestry-products biorefinery sector. Chapters 4 to 6 provide the theoretical foundations for systems of innovation and TIS, knowledge networks and generation, and leverage professionals respectively. These chapters support the subsequent associated analytical chapters.

Chapter 2 examined literature to understand the historical context, market developments and challenges facing the South African forestry-products sector. For the purposes of this study, it focused on pulp and paper manufacturing, and sawmilling. The environmental challenges faced by the sector were explored in some depth, as it is biorefineries that provide an opportunity to mitigate these. This chapter therefore provides the contextual foundation for the study and subsequent analysis (Chapters 7, 8 and 9).

Chapter 4 investigates the literature of systems of innovation (see Cooke et al., 1998; Cooke et al., 2007; Edquist, 2005a, 2005b; Lundvall, 1992, 2007a; Lundvall et al., 2002), focusing on TIS (see Bergek et al., 2008; Hekkert et al., 2007; Markard, 2018; Markard & Truffer, 2008), and the quadruple helix model of innovation systems, which argues for the incorporation of civil society as a critical actor in the innovation process (see Campbell et al., 2015; Carayannis et al., 2017; Cavallini et al., 2016; Grundel, 2017; Ivanova, 2014). Given South Africa's historical context of a divided society, it would be remiss of this study to neglect civil society as a core actor in the forestry-products biorefinery innovation system. As such, and amongst other approaches, a quadruple helix model offers this lens. Therefore, this chapter considers how the TIS approach is understood to act as the main theoretical thread running through the study. It also provides an assessment of the quadruple helix model, suggesting it to be more collaborative than other models as it explicitly acknowledges the role of civil society alongside government, industry and academia, as an equitable partner in the innovation process.

It is this theoretical underpinning that provided the basis for a set of criteria to determine the level of maturity, characteristics and collaborative status of the South African forestry-products biorefinery innovation process covered in Chapter 7. It also set the foundation to assess whether leverage professional knowledge and capabilities adequately echoed the requirements to enable a more collaborative innovative system to expedite biorefinery uptake.

The importance of knowledge and learning in systems of innovation literature is unpacked in Chapter 5. This includes the main theoretical arguments on how knowledge is generated, acquired and diffused. The chapter also interrogates the post-apartheid higher education policy debate, which has shifted an emphasis from codified to tacit knowledge production (Kraak, 2000, 2007; Musson, 2006). This debate has influenced interpretations of human capacity to enable innovation as a mechanism to enhance the country's economy (see SA Department of Trade and Industry, 2017; Mncwango, 2013; Mphahlele & Scerri, 2016; OECD, 2007; Roberts, 2006; Scerri, 2009, 2016b).

While the exploration of this literature provided a contextual understanding of knowledge generation and diffusion within systems of innovation framings, it did not provide an adequate enough theoretical foundation for understanding knowledge in terms of knowledge networks, knowledge generation and flows, and the types of knowledge held within a TIS. As such, this chapter also offers a critique of systems of innovation and the quadruple helix framework's view of knowledge and learning. This critique led me to literature on knowledge networks and social capital within an innovation context.

Section 3.3 describes how I drew on and enhanced systems of innovation literature to assess the social dimensions of knowledge and types of knowledge held in the South African forestry-products biorefinery innovation system.

Chapter 6 goes beyond conventional TIS literature. It drew on organisational literature to strengthen the argument that, for a forestry-products biorefinery innovation system to be more collaborative and effective, the role of individual change agents must be considered. This chapter therefore explores the theoretical concepts applied to ascertain the required characteristics and capabilities of such individuals. It also aids in the identification of the best combination of individuals to leverage change in the TIS.

This theoretical underpinning provided me with the confidence to incorporate the level of the individual within a TIS focused study. Section 6.2.1 highlights how this theoretical reference was used to develop criteria to assess the characteristics of leverage professionals operating in South Africa's forestry-products biorefinery innovation system. This reference was also used to critique of the current mix of individuals in the network.

3.2.2 Data sources and collection method

Documentary evidence and in-depth interviews with leverage professionals formed the main methods of data collection. Data gathered was analysed and formed the basis of three analytical chapters: Chapter 7 (the South African biorefinery innovation system), Chapter 8 (the knowledge network dynamics), and Chapter 9 (leverage professionals). All of them align with the theoretical foundations presented above.

3.2.3 Documentary evidence

Data and insights from documents were drawn on for all components of the study, most notably for Chapter 2 (the South African forestry-products and biorefinery context) and the theoretical information in Chapters 4, 5 and 6, which was used to inform the in-depth interviews and analysis chapters (7, 8 and 9), and to comment on and validate themes and findings emerging from the analysis. Two main sources of documentation were used:

1. *Primary research and academic literature*, such as journal articles, academic papers, monographs and published books and chapters. These provided an historical commentary on the South African forestry-products sector. They also validated biorefineries as an innovative solution to mitigating environmental impact. Finally, they provided the theoretical foundations for the study.
2. *Secondary publications*, such as government policies, strategies and reports; civil society reports; and grey literature such as e-zine articles, blogs and corporate websites were reviewed. They were used to assess who is contributing to biorefinery and associated topic discourse, and how it is used in the biorefinery innovation system. The sources also provided insight on collaborative innovation efforts, and actors and leverage professionals involved in the system. Contemporary commentary on

activities associated with the forestry-products sector and associated study themes was also garnered from these sources.

Where feasible, documentation published in the last five years was sought to ensure currency. However, older sources were used when setting historical and theoretical contexts.

3.2.4 In-depth interviews

Part of the rationale for this study is that, for significant uptake of biorefinery technologies to occur, leverage professionals are required in the TIS to make this happen. Pascale and Sternin (2005) argued that these individuals already exist within the system and are identified by their ability to adopt radically different approaches compared to their colleagues who operate within the same constraints. They sit within a wider network of colleagues on whom they rely to undertake or inform their work and the decisions they make (Jenkin et al., 2016). I suggest, that by understanding who these individuals are, it is possible to suggest the ideal consortium of individuals to form an effective and more collaborative TIS.

Thirty-nine leverage professionals operating within the broader South African forestry sector (including alien vegetation) were interviewed (see Table 1). The purpose of the interviews was threefold: First, to capture and explore their views, insights, experiences, motivation, challenges and learning pathways;[12] second, to obtain multiple viewpoints; and third, to reconstruct and challenge the theory developed during the research (Burawoy, 1998; Ghauri, 2004; Gill et al., 2008; Vithal & Jansen, 2010).

Interviewees were initially identified in consultation with Prof. Bruce Sithole, the Director and Chief Scientist in the Biorefinery Industry Development Facility at the Council for Scientific and Industrial Research (CSIR), and from my own professional network. Subsequently, they were also identified through grey literature and interviewee recommendations. They were selected on the basis of already being involved in biorefining or similar activities in South Africa, showed an interest in biorefineries as a solution to their waste issues, involved in national policy and/or had the potential to be involved in implementing a forestry-products biorefinery innovation system. Interviewees predominantly held design, engineering, technical

[12] A *learning pathway* refers to the courses and academic programmes individuals complete, and their learning experiences as they progress through their education and working careers (Great Schools Partnership, 2013). Similar terms include *knowledge pathways* and *educational pathways*.

and managerial roles. They were also identified as generators of innovation, as originators of research and development (R&D) (Kraak, 2007; OECD, 2007), and as change agents (Lotz-Sisitka, 2011; 2018).

Table 1: Leverage professionals interviewed

Leverage professional	Job title	Organisation
Government (including government delivery bodies)		
Garth Barnes	Deputy Director: Advocacy and Risk Management	Department of Environmental Affairs (DEA)
Johann Bester	Deputy Director: Technical and Information Services	Department of Agriculture, Fisheries and Forestry (DAFF)
Sunita Kalan	Director: Sector and Local Innovation	Department of Science and Technology (DST)
Steven Ngubane	Senior Project Manager: Agro-processing and Agriculture	Industrial Development Corporation (IDC)
Henry Nuwarinda	Project Manager	National Cleaner Production Centre (NCPC)
Tafadzwa Nyanzunda-Kadzombe	Director: Resource-based Industries	Department of Trade and Industry (DTI)
Dr Konanani Rashamuse	Director: Industry and Environments	DST
Kira Ross	Senior Manager: Business Optimisation and Special Projects	South African Forestry Company Limited (SAFCOL)
Christiaan Smit	Specialist: Wood and Lumber	
Industry (including trade and membership associations)		
Arianna Baldo	Lead: Africa/Middle East and Strategic Projects	Roundtable on Sustainable Biomaterials (RSB)
Dr Johan de Graaf	Executive Manager	Hans Merensky Holdings
Frans Hansen	Technical and Project Manager	Kimberly-Clark
Dr Ronald Heath	Director: Research and Protection	Forestry SA
Dr Arnulf Kanzler	Programme Leader: Tree Breeding, Shaw Research Centre	Sappi
Dr Dirk Längin	Forest Re-engineering Manager	Mondi SA
Mike Nash	Director: PAMSA Process Research Unit	PAMSA
Michael Peter	Executive Director	Forestry SA
Henry Reddy	Technical Services Manager	LignoTech
Petrus Saayman	Operations Director	Evergreen Timbers
Dr Nelson Sefara	General Manager: Sappi Technology Centre	Sappi
Roy Southey	Executive Director	Sawmilling SA
Grant Trebble	Project Advisor: Environmental Project Development	Independent

Leverage professional	Job title	Organisation
Jaco-Pierre van der Merwe	Wood Technologist	York Timbers
Anthony Williams	Managing Director	Citius Energy
Academia (including research institutions)		
Prof. Theo de Koker	Head of Programme: Pulp and Paper Technology	Durban University of Technology (DUT)
Prof. Linda Godfrey	Principal Scientist and Manager: Waste Research, Development and Innovation Roadmap Implementation; and Professor of Environmental Sciences and Management	CSIR and North West University
Prof. Johann Görgens	Director: Centre for Process Engineering	Stellenbosch University
Iain Kerr	Honorary Research Fellow, Chemical Engineering	University of KwaZulu-Natal (UKZN) and PAMSA
Dr Andrew Morris	Acting Director and Research Manager	Institute for Commercial Forestry Research (ICFR)
Dr Jimmy Pauck	Senior Lecturer: Pulp and Paper Technology	DUT
Prof. Bruce Sithole	Principal Researcher and Director of the Biorefinery Industry Development Facility; and Professor of Chemical Engineering	CSIR and UKZN
Dr Douglas Trotter	Competency Area Manager: Green Economy Solutions	CSIR
Civil Society		
Tjaša Bole-Rentel	Project Manager: Bioenergy	World Wide Fund for Nature South Africa (WWF-SA)
Amanda Dinan	Lead: Green Economy	Fetola Foundation
Bhavna Deonarain	Researcher	Trade and Industrial Policy Strategies (TIPS)
Saliem Fakir	Head: Policy Futures Unit	WWF-SA
Jarrod Lyons	Liaison: Green Economy Investment and Finance	GreenCape and Wesgro
Dr Bongani Maseko	General Manager: Agricultural Biotechnology	AfricaBio
Bongani Mthembu	Air Quality, GIS and Youth Development Officer	South Durban Community Environmental Alliance (SDCEA)

Adhering to the four quadruple-helix model actor groups, the interviewees represented government, industry, academia and research institutions, and civil society (see Table 2). See Appendix B for a full list of interviewee names, job titles, organisations and interview details.

Table 2: Numbers of leverage professionals interviewed, by actor group

Government	**No.**	**Industry**	**No.**
National government department	5	Private industry/business	10
Government-funded delivery-body	2	Trade associations	5
State-owned entity	2		
Total	**9**	**Total**	**15**
Academia	**No.**	**Civil society**	**No.**
Academia	4	NGOs	7
Research institution	4		
Total	**8**	**Total**	**7**

While only a selection of individuals was interviewed, it can be assumed they are a reasonable representation of individuals operating in the broader South African forestry-products biorefinery innovation system. It is appropriate to make this assumption, as key individuals in the system were identified and, in their interviews, they suggested other individuals for interview. This resulted in a common set of entities and individuals who were regularly referred to and formed a bounded network.

It should be noted that effort was made to identify and interview small- to medium-scale biorefinery companies. There are very few in the country and the eThala Group was the only small-scale entity to respond. However, they could not contribute to the study as they were not yet fully functional.

Table 3 presents the organisations represented by the leverage professionals interviewed along the forestry-products value chain. Given the focus on biorefineries, the majority fall within the plantation, milling and product manufacturing components of the value chain. This indicates where biorefinery feedstock and production opportunities could lie.

Interviews were semi-structured and recorded with most undertaken on site, with a few via video conference. There were two phases: The first was during preliminary fieldwork in August 2017 to test the theoretical premise of the study, with interviews held mainly with academic leverage professionals. The second phase was in August and September 2018, when interviews were held with a larger contingent.

The literature review provided an initial framework for interview question design. Questions were adapted as the research progressed and the developing theme and theory were challenged (see Appendix A for the guiding interview questions). While guided by structure, the conversation-led interview process enabled the participants to tell their stories. This allowed information on their work environment, education and employment pathways, perceived roles in the system, knowledge exchange and generation, and challenges to be captured.

Table 3: Leverage professional organisations represented along the forestry-products value chain

<table>
<tr><th>Actor group</th><th>Tree plantations / alien vegetation</th><th>Milling</th><th>Forestry-product manufacture</th><th>Use</th><th>Byproduct use / disposal</th></tr>
<tr><td rowspan="7">Government</td><td>Dept of Agric., Fisheries & Forestry (DAFF)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Dept of Environmental Affairs (DEA)</td></tr>
<tr><td></td><td></td><td colspan="3">Dept of Science & Technology (DST)</td></tr>
<tr><td></td><td colspan="2">Dept of Trade & Industry (DTI)</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Industrial Devlopment Corp. (IDC)</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">National Clearner Production Centre - South Africa (NCPC-SA)</td></tr>
<tr><td colspan="2">Safcol</td><td></td><td></td><td></td></tr>
<tr><td rowspan="12">Industry</td><td></td><td></td><td></td><td></td><td>Citius Energy</td></tr>
<tr><td></td><td>Evergreen Timbers</td><td></td><td></td><td></td></tr>
<tr><td>Forestry South Africa</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Hans Merensky</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Kimberly-Clark</td><td></td><td></td></tr>
<tr><td></td><td></td><td>LignoTech</td><td></td><td>LignoTech</td></tr>
<tr><td colspan="3">Mondi</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Paper Manufacturers Association of South Africa (PAMSA)</td></tr>
<tr><td></td><td></td><td colspan="3">Roundtable for Sustainable Biomaterials (RSB)</td></tr>
<tr><td colspan="3">Sappi</td><td></td><td></td></tr>
<tr><td></td><td>Sawmilling South Africa</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">York Timbers</td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Academia</td><td></td><td colspan="4">Council for Scientific & Industrial Research (CSIR)</td></tr>
<tr><td></td><td colspan="2">Durban University of Technology (DUT)</td><td></td><td></td></tr>
<tr><td>Inst. Commercial Forestry (ICFR)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Stellenbsoch University</td><td></td><td></td></tr>
<tr><td colspan="3">University of KwaZulu-Natal (UKZN)</td><td></td><td></td></tr>
<tr><td rowspan="6">Civil society</td><td colspan="4">AfricaBio</td><td></td></tr>
<tr><td colspan="3">Fetola</td><td></td><td></td></tr>
<tr><td colspan="5">GreenCape</td></tr>
<tr><td></td><td></td><td>South Dbn. Com. Env. Alliance (SDCEA)</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Trade & Industrial Policy Strategies (TIPS)</td></tr>
<tr><td colspan="5">World Wide Fund - South Africa (WWF-SA)</td></tr>
</table>

3.2.5 Validity and reliability

Validity in empirical education research refers to the testing of the accuracy level of the research hypothesis, and the meaningfulness and usefulness of the measures used (Peeters et al., 2013). Interview transcripts were compared to and validated with theoretical framework concepts and academic research. To further corroborate the study's hypothesis, critiques of the broader principles of innovation systems literature, knowledge networks, knowledge generation and diffusion, and leverage professionals as change agents were considered.

As this study is qualitative, precise replicability as a form of reliability was not feasible. This is because human subjects cannot be confirmed or conformed. This was the case when I analysed leverage professional interview transcripts. Through my interaction with the transcripts, I interpreted an "interrelated practice of statements" (Engelhardt, 2015, p. 134) to develop a common set of patterns of knowledge and meaning from a collective body of knowledge (Engelhardt, 2015; Starks & Brown Trinidad, 2007).

Transcript analysis involved coding themes into the three overarching elements of this study: the biorefinery innovation system; level of collaboration; knowledge network, generation and diffusion; and leverage professionals. While these central themes remained unchanged, the sub-themes were refined during the analysis.

Given the interpretative nature of analysing the interview transcripts, I acknowledge my role as researcher and therefore the influence this has on their interpretation. Starks and Brown Trinidad (2007) noted that, by adopting this analytical method, researchers should recognise their role in the process. To mitigate this, they should ensure rigour and trustworthiness throughout. Accordingly, criteria cited by Noble and Smith (2015) were adopted to evaluate the credibility of the research findings.

3.2.6 Ethical considerations

Areas of ethical concern were considered because participants revealed aspects of their personal and workplace practices. These revelations might have been confidential or required high levels of sensitivity. Given the significance of the leverage professionals insights, it was decided they should be named in the study. If they were not, I felt the integrity of their voices would be lost. As such, all interviewees were asked for permission to be named, and all gave recorded and transcribed consent.

In addition, the requirement and process for participants to be named was approved by the University of Witwatersrand's Ethics Committee. While permission was given by leverage professionals to be named, I adopted the protocol of treading lightly and exercised caution when considering citing them in the study.

3.3 Methods of analysis

Research analysis tools and frameworks that did not elicit a one-dimensional lens were selected. These were, firstly, a political, economic, social and environmental context of the forestry-products sector; second, an approach that enabled an understanding of the collaborative dimensions of the functions and characteristics of the biorefinery innovation system and associated knowledge network; and thirdly, a mechanism for identifying and researching the leverage professionals within the system. As a result, this section provides an overview of the research methods applied for the analytical evidence base for Chapters 7, 8 and 9.

3.3.1 The technological innovation system approach

Core foundational literature on technological innovation systems (TIS), in particular those associated with eco-innovations, was used to guide the analysis of South Africa's forestry-products biorefinery innovation system. This literature was the works of Bergek et al. (2008), Markard and Truffer (2008), Negro (2007) and Walz et al. (2016). Their works provided an in-depth framework for investigating technical innovations that responded to sustainability challenges. Negro's case study specifically focused on biomass. The literature firmly set TIS as a contextual framing encompassing actors within a network, and a secure environment in which the innovation process can occur (Geels & Raven, 2006; Markard & Truffer, 2008; Negro, 2007; Rotmans & Loorbach, 2009; Uriona & Vaz, 2017).

At the macro-level, the overarching broader socio-economic structure and context of the TIS was considered (Negro, 2007; Walz et al., 2016), for example, the environmental challenges, and transition from a fossil-fuel to a biofuel-based economy. At the actor-level, human resource dynamics, system functions, and biorefinery technologies and products were investigated (Geels & Verbong, 2007; Markard & Truffer, 2008; Negro, 2007; Rotmans & Loorbach, 2009; Uriona & Vaz, 2017).

South Africa-specific literature proved pivotal for providing conceptual and empirical insight, and a critique of South Africa's innovation system(s). Examples are *The emergence of systems* *of innovation in South(ern) Africa: Long histories and contemporary debates* by Scerri (2016a) and *Towards inclusive and responsible technological innovation systems* by Douglas (2019).

Functionality of the South African forestry-products biorefinery innovation system

The purpose of this analysis was to describe the forestry-products biorefinery innovation system, and how well the current system functions against a set of indicators. Each function should occur within, and contribute to, the overall functioning and performance of the TIS (Bergek et al., 2008; Hekkert et al., 2007; Negro, 2007; Uriona & Vaz, 2017). Various lists of TIS functions have been developed (see Bergek et al., 2008; Bergek et al., 2010; Hekkert et al., 2007; Johnson, 1998; Uriona & Vaz, 2017; Walz et al., 2016). These were consolidated into the following for my analysis:

1. Knowledge generation and diffusion through networks
2. Influence of direction of the research
3. Entrepreneurial activities and experimentation
4. Market formation
5. Legitimisation of biorefinery technologies
6. Resource mobilisation

See Appendix C for further detail on function descriptions and indicators, and Chapter 7 for use in the analysis.

Assessment of the maturity of a TIS

Markard (2018) suggested assessing the maturity of a TIS by using a life-cycle approach. He argued that a TIS will progress through a series of phases (formative, growth, mature and decline phases) as its structure, processes and functions change over time. These phases are presented in Table 4, which provides a matrix of variables and components against each phase. This provided a framework for assessing the maturity of South Africa's forestry-products biorefinery innovation system.

Table 4: The four phases of a technological innovation system (TIS) life cycle used to ascertain the maturity of the South African forestry-products biorefinery innovation system[13]

Formative phase	Growth phase	Mature phase	Decline phase
Size and actor base			
− Sales close to zero − Little growth − Small number of actors − Significant vertical integration − No specialist suppliers − Low entry/exit rates	− Sales are moderate at first but grow rapidly − Shift to expansion − Medium to large number of actors in different roles − Specific associations and intermediaries emerge − High entry rates − Process of cumulative causation − Strong competition	− Sales are high − Low growth − Medium to large number of actors − High degree of specialisation − Low entry/exit rates − Potentially dominant players − Little conflict	− Sales below maximum and declining − High exit rates − Intermediaries lose influence − Increasing institutional conflicts
Institutional structure and networks			
− Low structuration − High degree of uncertainty − Universities central − Loose networks and rudimentary structure − No value chains − Intentional strategic action − Finance focused on R&D − Public agency funding	− Increasing structure − Markets take shape − Technology-specific organisations emerge − Increasing formalisation − Collaboration in networks	− High degree of structuration − Uncertainty low − Established markets − Value chains and networks	− Structural decentralisation − Norms and designs questioned − Networks break up

[13] Adapted from and informed by Bergek et al., 2008; Hellsmark et al., 2016; Markard, 2018; Musiolik et al., 2012.

Formative phase	Growth phase	Mature phase	Decline phase
Technology performance and variation			
− Performance parameters unclear − Performance low compared to existing technology − High degree of variation − Focus mainly on R&D, experimentation and prototyping	− Performance parameters clear − Performance increasing − Variation decreasing − Potential emergence of dominant design	− Performance increasing − Potential branching of technology to new application contexts	− Performance parameters potentially questioned
Context and TIS-context relationship			
− TIS depends on context − TIS actors manage the context − First ties emerge	− Ties to context multiply and formalise − TIS has increased impact on context − Potential conflicts arise	− High number of close ties − Interaction of TIS and context − Co-dependence	− Ties break up − Dependent context structures decline as well

Assessment of a collaborative and effective system of innovation

I drew on quadruple helix framework and social capital[14] literature to develop criteria to assess the level of coordination, collaboration, relationships and knowledge transfer in the biorefinery innovation system. These criteria, presented in Table 5, propose determinants for an ideal collaborative TIS.

Table 5: Proposed criteria for assessing an ideal collaborative and effective technological innovation system[15]

Characteristics	Determinants
Actors	− Industry (including trade associations), academic and research institutions, government departments and civil society representation
Governance	− Collaborative and participatory − Promotion of routine interaction between all four actor groups − Limited or no monopoly by one actor or more − Decentralised sharing policy and pact
Complex trust	− Interpersonal or mutual trust − Recognition of a larger purpose (i.e., beyond the individual/ organisation) − Provision of time and commitment to develop trust through collaboration
Translation, language and communication	− Recognition of different languages, yet creating a common language − Governance structure, procedures, flows of information, confidentiality, intellectual property (IP) and evaluation criteria clarity − Adoption of a collaborative problem-solving approach − Recognition of *pure* and applied research and experience − Recognition of local and “universal knowledge” − Translators to facilitate knowledge exchange, and theory or scientific knowledge into something that is economically useful
Negotiation	− Collective decision making that requires bargaining and deliberation − Capacity and ability to manage and resolve conflict and solve problems − Reciprocal respect of participant interests
Network ownership and governance	− Equity of power and leadership between the actors − Approach and structure to design, implement and maintain the TIS − Network coordination and management capabilities and skills − Shared vision, values and strategy
Demonstration	− Recognition that the benefits of collaborative innovation will emerge through demonstration (requires trust) − Research to demonstrate possibility, and ability to improve uptake − Learning and internalising tacit knowledge and skills held by partners

[14] Social capital is defined as a set of shared values, norms, routines and practices across a network of personal relationships (McFadyen & Cannella, 2004; Nahapiet & Ghoshal, 1998; Putnam, 1993). A theoretical underpinning of the concept is explored in Chapter 5.

[15] Sources: Botha et al., 2016; Bouraoui et al., 2011; Culpepper, 2003; Lindberg & Teras, 2014; Luna & Velasco, 2010; Manzini, 2015; Markides, 2005; Morris & Barnes, 2006; Nahapiet & Ghoshal, 1998.

Characteristics	Determinants
Mutual benefaction	− Acquisition (through sharing) of information, knowledge, understanding, know-how, techniques and practices that lead to beneficial change − Alliances need to be mutually strategic
Social impact	− Considers social impact of innovations
Efficacy and efficiency	− Capacity, knowledge and skills to produce and meet intended outcomes and goals − Problem-solving at the lowest possible cost − Benefits yielded fairly to each actor

This set of criteria was used in the analytical chapters 8 and 9 on the dynamics of the knowledge network, and characteristics and behavioural preferences of the leverage professionals respectively. By assessing the findings against these criteria, it was possible to determine whether the current biorefinery innovation system presented any gaps in comparison to the ideal. If so, it was possible to consider whether these gaps presented a reason why the current system might not be as collaborative or effective as it could be.

3.3.2 Understanding knowledge and social capital

While I could relate to the TIS framework's knowledge-based view in Functions 2 and 3, I found the framework's function criteria limiting[16] in terms of the level of detail I wished to explore to understand knowledge generation, acquisition and exchange in the system. For example, TIS determines these functions through the quantification of the number of R&D projects, patents and investments associated with an innovation or it assesses how many workshops or conferences were held on a topic. This lens meant elements such as how knowledge is generated and exchanged, who holds it, and the types of knowledge held in the network would be neglected if I adopted the function criteria listed above.

Given these limitations, I initially explored social network analysis methods (such as those of Boertjes et al., 2011, and Cronin, 2015) to discover knowledge dynamics in the TIS. However, while social network analysis enables connections between actors and individuals to be mapped, it is criticised for focusing too much on data analysis. Rather, it is argued, it should focus on understanding how organisations network or cluster (Salancik, 1995). Social network analysis also did not allow for the mapping and understanding of who holds, generates and diffuses knowledge and how it flows in the biorefinery innovation system. Hence, further

[16] See Appendix C for TIS function descriptions and indicators.

reading brought me to two pieces of research. The first was the work of Nahapiet and Ghoshal (1998), who presented an analytical framework for assessing social capital and knowledge creation. The second was by Sammarra and Biggiero (2008), who provided a method for assessing knowledge flows in innovation networks.

While Sammarra and Biggiero's (2008) method focuses on inter-firm knowledge flows, elements of their method provided a platform that could be easily transferred and adopted for investigating a system's knowledge network. Nahapiet and Ghoshal (1998) on the other hand, proposed parameters for assessing the dimensions of a knowledge network: structural, relational and cognitive.

Structural dimension of the knowledge network

The structural dimension of a knowledge network covers the channels through which interaction is facilitated and knowledge is generated and transferred (Nahapiet & Ghoshal, 1998; Sułkowski, 2017; Van Reijsen, 2014). It includes:

- the network and linkages of individuals who exchange knowledge (van Reijsen, 2014)
- commentary on the strength and cohesiveness of the ties between individuals (ascertained through frequency and direct interaction) (Bonfim et al., 2018; Nahapiet & Ghoshal, 1998)
- diversity of the individuals within the knowledge network – an indicator of network strength (Nahapiet & Ghoshal, 1998)

While this framework provided an approach to describe the structural characteristics of the knowledge network, it did not provide a mechanism for mapping the network. As such, I initially began to map the network by hand, but it became clear this would be time-intensive and impractical. While searching for a programme to replicate this task, I came across work undertaken by Li et al. (2018). They had mapped the knowledge flows associated with an eco-centre in Australia. Their process and programme used to visually map the knowledge flows resonated because it enabled the development of an algorithm to map knowledge flows between actors and leverage professionals. In addition, and of relevance to the study, the research by Li et al. (2018) was set in an environmental context. Li et al. (2018) used the computer program Gephi to develop their knowledge network maps, also referred to as "sociograms" (Moreno,

1934) or “visual network analyses”.[17] This proved to be an incredibly valuable discovery for this study. It enabled me to run data (nodal and edges) gathered from the interviews to develop the social networks (sociograms) associated with the South African forestry-products biorefinery innovation actor network (Figure 6) and the centrality of leverage professionals within the network (Figure 7). The “node” represented an actor group cited by a leverage professional, and the “edges” represented the links between actor groups. As such, the sociograms present an indicative structure and the connections between actors in biorefinery innovation system. In addition, the size of the nodes represented the number of connections per actor, and therefore their centrality and position within the network (Grandjean, 2015).

The sociograms reflect only a selected representation of the network and not the full network of actors or leverage professionals in the system. However, the map can be assumed to be reasonably indicative as it identified key individuals in the system. In addition, leverage professionals suggested additional actors or individuals to consult in their interviews. This demonstrates that certain actors and individuals were referred to regularly, which indicated some form of circular and bounded network. Rickne (2000), in her thesis on biomaterials technological systems in Sweden and the United States, noted that (as with this study) the incomplete identification of all actors is recognised as a difficult task. This is particularly the case for an emerging system of biomaterials, such as South Africa’s forestry-products biorefinery network.

Relational dimension of the knowledge network

Where the structural dimension captures channels, the relation dimension captures the common language, shared values and trust held in a knowledge network (aka social capital) (Bonfim et al., 2018; Moos et al., 2012; Nahapiet & Ghoshal, 1998; van Reijsen, 2014). Nahapiet and Ghoshal (1998) suggested that these elements, or the lack thereof, can either enable or inhibit effective and efficient knowledge exchange.

Analysis of leverage professional interview transcripts allowed relational dimensions to be identified and analysed. This was explored in terms of the value of shared knowledge, and what

[17] The computer program principles of visual network analysis are covered by Venturini et al. (2014), and Gephi principles are covered more specifically by Bastian et al. (2009).

I refer to as the “knowing of each other”, use of a common language and levels of trust. Interviewee quotes are used in this study to demonstrate the importance of these variables.

Cognitive dimension of the knowledge network

The third dimension assessed was cognition, which encapsulates the shared language, codes and narratives held within the knowledge network (Bonfim et al., 2018; Nahapiet & Ghoshal, 1998). Nahapiet and Ghoshal (1998) suggest that these cognitive commonalities expedite knowledge transfer due to an enhanced understanding between individuals in a network. For the purposes of this study, I focused on the commonalities of understanding of the biorefinery concept in interview transcripts and key South African literature (notably CSIR, 2017; (SA Department of Science and Technology, 2013, 2018a, 2018b; Görgens et al., 2015). From this exercise, it was evident that definitions and understanding varied within the network.

Knowledge generation and acquisition within the biorefinery innovation system

As highlighted, knowledge generation, more specifically learning, is a core element of systems of innovation discourse (discussed further in Chapter 5) (see for example Borrás & Edquist, 2014; Brenner, 2007; Jensen et al., 2007; Lundvall & Lorenz, 2007). This is recognised in the context of two main modes of knowledge generation: codified and tacit. Lundvall and Lorenz (2007) expanded on this by referring to the science, technology and innovation (STI) and the doing, using and interacting (DUI) modes of learning. This distinction provided a useful framework for assessing and categorising knowledge generation and acquisition within the forestry-products biorefinery innovation system. It also provided a more holistic understanding of the way knowledge is generated and learning takes place. This as opposed to the application of the framework to assess the function of knowledge generation in a TIS. The TIS function, while focusing on the importance of “learning-by-searching” and “learning-by-doing”, tends to assess only a narrow set of quantitative indicators: the number of and investment in research and development projects, and the number of patents associated with a technology (Hekkert et al., 2007; Uriona & Vaz, 2017).

Drawing on the above, a knowledge inventory was developed to assess knowledge generation and acquisition within the network. This was informed by the work of Nonaka and Takeuchi (1995). They categorised codified knowledge (Mode 1) into systemic and conceptual knowledge, and tacit knowledge (Mode 2) into experiential knowledge and routine knowledge (see Table 6). I used an adapted version of their framework to assess the mechanisms used by leverage professionals to generate and acquire knowledge within the forestry-products biorefinery knowledge network.

Table 6: Framework used to analyse the mechanisms for generating and acquiring knowledge[18]

Codified knowledge	**Tacit knowledge**
Systemic knowledge	**Experiential knowledge**
Definition characteristics − Systematised and packaged knowledge − Pre-tested and paradigm-based, objective scientific methods − Know-what – for example, scientific results, specifications, manuals, databases, patents and licences − Know-why – an understanding of the context of an innovation	**Definition characteristics** − Know-how – individuals' skills to perform dynamic problem solving, and practical experience generated from common experiences − Mission-oriented R&D − Know-who – the relationships and interactions between actors and individuals − Includes dimensions, such as caring, love, personal energy, emotion, attitude, thoughts, passion, tension and trust
Mechanisms for obtaining systemic knowledge − Transmitted using formal language, such as rules, procedures, laws, and principles − Obtained through reading books, theses, journals, attending lectures and academic conferences − Delivered as educational content and through curricula	**Mechanisms for obtaining experiential knowledge** − Acquired through on-the-job learning, by using or doing, for example, hands-on practice and observation − Through collaboration (communities of practice) − Dealings with customers
Conceptual knowledge	**Routine knowledge**
Definition characteristics − Articulated through images, symbols and language (semiotics) − Product concepts, design and brand equity − Perceptions held by customers and employees of an organisation	**Definition characteristics** − Routine knowledge embedded in actions and practices that are internalised over time − Know-how in daily operations − Organisation routine and structure

I explain how I applied this quadrant of knowledge generation in Chapter 8. It was used to review leverage professional interview transcripts for how they generated, acquired and exchanged knowledge. Each citing was captured and inserted into a matrix based on the quadrant criteria. This resulted in an extensive list of knowledge generated, acquired and exchanged in the biorefinery knowledge network. From this exercise, it was possible to determine which type of knowledge was prominent, as well as the main mechanisms for exchanging knowledge.

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[18] Adapted from Nonaka and Takeuchi (1995). Definitions and mechanism sources: Al-Laham et al., 2011; Bresnen & Burrell, 2013; Dinur, 2011; Gibbons, 1998; Hessels & Van Lente, 2010; Jensen et al., 2007; Lundvall & Lorenz, 2007; Muller & Taylor, 2012; Nonaka & Takeuchi, 1995; Piperca et al., 2009; Toivanen & Lima-Toivanen, 2009; Wenger, 2013; Witt & Zellner, 2007.

In addition to the use of the quadrant, interview transcripts were analysed to identify core themes relating to knowledge generation and acquisition. Notable themes were the importance of work-based learning to the sector, issues of trust and knowledge lock-in.

Knowledge transfer and diffusion within the biorefinery innovation system

The transfer of knowledge was identified as the TIS function "knowledge diffusion", where indicators include "the number of workshops and conferences on the topic" and "intensity of these over time" (Bergek et al., 2010; Coenen, 2010; Hekkert et al., 2007; Markard, 2018; Negro, 2007; Uriona & Vaz, 2017; Walz et al., 2016). However, these variables do not capture all the dynamics of knowledge exchange. For this reason, I referred to the work of Gosselin et al. (2018), who sought to understand how knowledge is transferred between environmental science and management. Three knowledge transfer interfaces were suggested:

- *Trickle-down:* a linear model where researchers produce research and users adopt the findings with little effort
- *Transfer-and-translate:* where scientists (in Gosselin et al.'s case) try to translate their results in a comprehensive way and users test the results for feasibility and relevance
- *User-push:* where users commission researchers to produce knowledge on topics of interest and relevance to them.

These three interfaces, in combination with Dinur's (2011) taxonomy of knowledge transfer mechanisms, provided a lens for interpreting the dynamics of knowledge transfer in the South African forestry-products biorefinery knowledge network.

Knowledge held within the network

A diversity of knowledge types are deemed necessary to exist within a TIS's knowledge network for innovation development and implementation to occur (see Bouraoui et al., 2011; Culpepper, 2003; Lindberg & Teras, 2014; Luna & Velasco, 2010; Markides, 2005 and Morris & Barnes, 2006). Table 7 draws on the work of numerous authors to present a consolidated set of knowledge type classifications. These classifications were used as the framework of analysis in this study.

Table 7: Knowledge type classification[19]

Knowledge stock type	Description
Market or entrepreneurial	Includes knowledge on market conditions, opportunities and risks; future markets; customer relations, preferences, applications and expectations; competitor knowledge.
Technological	Includes specialist foundational knowledge of a product or service; blueprints, product analyses, designs, research and development; knowledge, skills and experience on materials, suppliers and products; scientific knowledge; recognition of new technologies and technical practices; knowledge of production systems and principles.
Product	Includes knowledge about a product landscape.
Process, procedural or managerial	Includes managing and designing internal processes; project management know-how and skills (from concept through to implementation); how to efficiently and effectively coordinate and supervise a team; use of knowledge management systems; how to share knowledge, integrate, interpret and apply it to aid the performance of project tasks; strategic networking capabilities.
Organisational	Includes understanding of organisational forms, structure, systems and functions; how to strategically capitalise on existing resources; linked to people (can be intangible).

Drawing on this classification framework, knowledge types held and illustrated by the leverage professionals were assessed from two positions: (a) that held by the individual (i.e. personal knowledge); and (b) the type of knowledge exchanged within the network.

3.3.3 Leverage professional analysis

Defining a leverage professional

The term leverage professional is an abstract concept I developed for the purpose of this study. “Leverage” refers to the role individuals play as catalysers (levers of change) within the forestry-products biorefinery innovation system. “Professional” refers to their qualification and peer status in terms of the level of education and experience. The theoretical foundation for this term is covered in Chapter 6.

Leverage professional classification

Given the recognition of the leverage professionals within this study, I felt it important to better understand the role they played within the system. This included how they were connected and supported each other (social capital), as well as whether their traits or challenges determined

[19] Adapted from and informed by: Abernathy & Clark, 1985; Bartsch et al., 2013; Biggiero et al., 2016; Burgers et al., 2008; Chao et al., 2014; Cross & Baird, 2000; Dinur, 2011; Haapalainen & Kantola, 2015; Hult et al., 2007; Moos et al., 2012; Nordqvist & Frishammar, 2018; Piperca et al., 2009; Sammarra & Biggiero, 2008; Van Waveren et al., 2014; Yli-Renko et al., 2001.

their ability to function within the system. No systems of innovation literature provided an adequate framework for this type of analysis.

Organisational theory and literature provided the most aligned approaches to undertake this analysis, particularly about how individuals operate in teams, team dynamics and the composition of high-performing teams. As little knowledge network or social capital literature captured this element, I adopted the concept of a "team" *t*o refer to the knowledge network.

Of the approaches identified, Belbin's team role taxonomy provided the most useful classification. It identifies nine individual behavioural profiles required as a combination within a team [aka the knowledge network] to perform well, and be effective and well balanced (Belbin, 2019). This fit well with the formulation of an effective and more collaborative TIS. Belbin's taxonomy has a strong analytical foundation, having been applied across various sectors and sizes of organisation. It has also been cited and adopted in academic studies and literature (for example, Flores-Parra et al., 2018, Gibson & Nesbit, 2006; Higgs, 1996, Mostert, 2015; Swailes & McIntyre-Batty, 2002). By combining Belbin's team role taxonomy with knowledge network analysis, it was possible to strengthen the approach. This allowed the analysis of relationships between and characteristics of leverage professionals in the system. A similar combination of approaches was adopted by Flores-Parra et al. (2018) in their study *Towards team formation using Belbin role types and a social networks analysis approach*.

In combination with Belbin's taxonomy, other individual role classifications were identified (and are explored in depth in Chapter 6). These included:

- boundary spanners (Aldrich & Herker, 1977; Safford et al., 2017; Tushman & Scanlan, 1981)
- brokers (Burt, 2005)
- intermediaries (Hermann et al., 2016; Kanda et al., 2018)
- change agents (Caldwell, 2003; Kraft, 2017; Lotz-Sisitka, 2011; Pascale & Sternin, 2005)
- system builders (Musiolik et al., 2016)
- tempered radicals and positive deviants (Meyerson, 2001, 2004; Pascale et al., 2011).

This combination formed a hybrid classification (see Table 8) for assessing leverage professional characteristics. This classification was used to assess whether the current combination of leverage professionals formed an effective network to enable increased uptake of biorefinery technologies in the country. See Appendix D for a detailed set of classification descriptions.

Table 8: Hybrid classification of individual team [aka network] roles[20]

Belbin team role type	Belbin role descriptions	Aligned individual role classifications: Boundary spanner	Broker	Intermediary	Change agent	Tempered radical	Positive deviant
Coordinator	A person who is mature, confident and identifies talent. They clarify goals, and coordinate and control team activities.	x	x		x		
Resource-investigator	Uses their inquisitive nature to find ideas, and identify opportunities, to bring back to the team. They are outgoing [extrovert] and enthusiastic; and develop [outside] contacts.	x	x	x	x		
Team worker	Helps a team to get along, using their versatility to identify the work required to complete a task or project. They are cooperative, perceptive, diplomatic and people-oriented. They have good communication skills and listen to mitigate friction.	x	x		x		
Plant	Tends to be highly creative and good at solving problems in unconventional ways. They are imaginative, free-thinking idea generators and problem-solvers.	x	x		x	x	x
Monitor-evaluator	Is sober, strategic and discerning. They see all options and are good judges of accuracy.	x					x
Implementer	Required to plan a workable strategy and carry it out as efficiently as possible. They are practical, reliable and efficient, and can turn ideas into actions, while also organising the work that needs to be done.	x			x		
Completer-finisher	Is painstaking, conscientious and often anxious. They search out errors and adopt a perfectionist approach.						
Shaper	Is challenging, dynamic and thrives on pressure. They have the drive and courage to overcome obstacles.				x	x	x
Specialist	Brings in-depth specialist knowledge of a key area and skills to the team. They are known for being single-minded, self-starting and dedicated.	x	x		x		

[20] Adapted from and informed by: Aldrich & Herker, 1977; Belbin, 2010, 2019; Caldwell, 2003; Hermann et al., 2016; Kanda et al., 2018; Kraft, 2017; Lotz-Sisitka, 2011; Meyerson, 2001, 2004; Musiolik et al., 2016; Pascale & Sternin, 2005; Pascale et al., 2011; Quinn & Meyerson, 2008; Safford et al., 2017; Tushman & Scanlan, 1981.

When assessing the role of leverage professionals within the system, it was also assumed that they can play two roles: (a) as an individual within the system, bringing their passion, drive and leadership qualities, for example; and (b) as an individual employed in an organisation. For the latter, their identity is interpreted as being organisation- or group-oriented.

3.4 Limitations and assumptions

This research method and structure chapter illustrates that this study did not confine itself to one analytical framework. It drew on a TIS framework and other organisational literature to aid an in-depth assessment of South Africa's forestry-products biorefinery innovation system, how collaborative it is, its associated knowledge network and the individuals within it.

It also did not adhere strictly to the statistical and qualitative forms of network analysis applied in economic or organisational studies but was guided by them. To ensure theoretical and analytical cohesiveness, however, overarching systems of innovation constructs, with a focus on TIS, were used as the overarching theoretical framework (as illustrated in Figure 2).

One of the main overarching concerns in qualitative research is that the researcher's biases will interfere with the structure and interpretation of data (Rovai et al., 2013). To acknowledge my researcher bias, I ensured integrity and rigour throughout by being transparent about how my preconceived ideas, knowledge or work experiences might have influenced the data analysis and conclusions. As such, I embraced my presence as an active partner in the leverage professional interviews. Holstein and Gubrium (1997, p. 113) recognised this as "active interviewing". O'Rourke and Pitt (2007) suggested that, by recognising their interactive role within the interviews, researchers can garner richer insights from the interviews.

As noted previously, a limitation of interviewing a selection of leverage professionals is that full representation of the forestry-products biorefinery innovation system is not captured. To mitigate this, the selection of participants was methodologically rigorous and cross-checked with Prof. Sithole and other experts within the sector. This meant variability was ensured, and a similar spectrum of responses was obtained from all four quadruple helix actor groups.

With regard to assumptions, I started with two. The first was that effective, transformative change and adoption of biorefinery technologies required a system of enhanced collaborative innovation (explicitly including civil society) and knowledge diffusion. The second was that the effective functioning of the TIS and increased adoption of biorefinery technologies relied on key leverage professionals.

3.5 Conclusion

To investigate and answer the fundamental questions proposed by this research, four main methods of analysis were adopted. First was the TIS framework for assessing the level of collaboration, maturity and functionality of the forestry-products biorefinery innovation system. Second was the quadruple helix framework which explicitly acknowledged civil society as an equitable actor within the innovation process. Third was the knowledge network analysis and the social capital construct to understand the connectedness of those operating within the TIS, and the strength of the ties, commonalities and challenges. Finally, Belbin and other individual team role classifications were combined to characterise leverage professional traits. This was to ascertain the combination of knowledge and capabilities to expedite the uptake of biorefinery technologies in the country.

The TIS framework, and where appropriate overarching innovation system constructs, underpins all elements of analysis to ensure alignment and compatibility throughout. By adopting such an approach, a form of praxis is provided to contribute to TIS research, but with a focus on knowledge and leverage professionals within the network. The latter, as previously noted, was not captured in most innovation system literatures to the level I wished to investigate.

Chapter 4:
Collaborative innovation systems

The premise of this study was that the increased adoption of biorefinery innovations by the forestry-products sector in South Africa would require improved collaboration, acknowledging a diversity of actors representing government, industry, academia and civil society. Given this ambition, systems of innovation theory, with an explicit orientation towards technological systems of innovation (TIS) was identified as the most appropriate theoretical foundation for the study, around which other theoretical and empirical dimensions were centred.

While a diversity of theories exist in the field of innovation (Faissal Bassis & Armellini, 2018), the systems of innovation body of theory was selected for three main reasons: first, its level of maturity; secondly, its definition(s); and thirdly, the centrality of knowledge and learning in the innovation process. Having been in existence for almost 30 years, systems of innovation discourse has reached a high level of maturity. This has been achieved through a critique of its foundations and core concepts (Faissal Bassis & Armellini, 2018; Lundvall, 2007b). It offers a systems approach for analysing economic and technical change (Carlsson et al., 2002). In addition, and of relevance to this study, is how systems of innovation are defined by three of its founders. They place emphasis on relationships and interactions, as illustrated below:

- "the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge … includes all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring" (Lundvall, 1992, p. 12).
- "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987, p. 1).
- "a set of institutional actors that, together, plays the major role in influencing innovative performance" (Nelson, 1993, pp. 4–5).

This emphasis on interaction relationships is key because it is through this interaction that innovation is developed, adapted and adopted for economic development. Knowledge is also generated and transferred to support innovation development and adoption. This is explored further below.

This chapter provides, firstly, an introduction to some key concepts; secondly, a review of the literature to explore the development of systems of innovation discourse; and thirdly, a focus on TIS as the core theoretical framework around which this study is oriented. While there are other levels or sub-systems sitting under the broader umbrella of innovation systems, such as national, regional, sectoral and organisational, the TIS application explores specifically the relationships between actors and the systemic determinants (such as functions and structure) of technological change and economic development (Bergek et al., 2008; Hekkert et al., 2007; Markard, 2018; Markard & Truffer, 2008; Uriona & Vaz, 2017). The final section of the chapter explores the quadruple helix model. This is a relatively new concept and framework within the broader system of innovation narrative, which recognises the complexity of the context and collaborative dimensions of interactions between actors within the system, with particular reference to four sets of actors - government, industry, academia and civil society (Campbell et al., 2015; Carayannis & Campbell, 2011; Carayannis et al., 2017; Cavallini et al., 2016a; Grundel, 2017). In principle it criticises systems of innovation thinking for neglecting civil society, calling it "narrow-minded and undemocratic", because of this exclusion (Grundel, 2017, p.1; Ivanova, 2014). I argue that the inclusion of civil society is crucial in a more collaborative TIS, especially given South Africa's historical context. For this reason, the constructs of the quadruple helix model are used to assess the level of collaboration in the forestry-products biorefinery innovation system.

4.1 Some key concepts

Innovation and collaboration are defined in this section.

4.1.1 Innovation as a concept

Prior to developing an understanding and historical context of systems of innovation theory, it is worthwhile addressing the concept of "innovation" and its role in economic development. Lundvall (2007a), in his paper on the history of innovation system research, suggested the concept of innovation was first recognised by the economist and philosopher, Adam Smith. In his seminal work of 1776, *The wealth of nations,*[21] innovation occupies a key role in economic development.

[21] For a recent edition of this work, see Smith (2014).

Writing in the 1930s and 1940s, Joseph Schumpeter (widely considered the founder of innovation research and evolutionary economic theory) defined innovation as a combination of factors presented or carried out in a new way (Cooke et al., 1998; Edquist, 2005b). Edquist (2005a), a systems of innovation theorist, suggested innovations can be both technological and organisational within a technological context. Therefore, for the purposes of this study, this is useful as this study covers both: biorefineries (technological) and a multi-actor collaborative model (organisational). This idea is captured by Cooke et al. (1998, pp. 1569-1570), who acknowledged the interactive dimension of innovation, in which the interactive process allows new knowledge to be "transformed into commercial or other practical uses". Scerri (2009, p. 227) suggested that this distinction between technological and organisational (or, as he refers to it, "human factor") is important when analysing systems of innovation. He argued that it is the human element that determines patterns of ownership and control over innovation.

Catalysts for innovation within systems of innovation can be multiple. The multiplicity distinguishes it from the historically linear concept of innovation. This is when innovation is generated or prescribed by scientists and technologists alone (Cooke et al., 1998). Coenen et al. (2017) in their work on the historical frameworks of system of innovation policy, suggest that this linear process has a bias towards technological discovery. It does not adequately incorporate the use of knowledge in the process. Knowledge within the process, they argued, provides the enabler for transitioning from ideation to application (praxis). This view is supported by Edquist (2005a), in his work on the development of systems of innovation approaches. In this work, he builds on this and suggests the generation of an innovation is complex and interactive. It draws not only on knowledge but also science, technology, learning, production, policy and demand. In addition, for the system of interactions to be effective and operative, Witt and Zellner (2007) suggest the coordination of physical and human resources are also an important element of the innovation process. This statement is important for this study, as it highlights the need to consider individuals within the system who can coordinate and manage resources as a process.

4.1.2 Defining collaboration

As has been highlighted above, and by others, the interactive process is core to the innovation process (for example, Cooke et al., 1998; Edquist, 2005a; Lundvall, 1992, 2016a; Nelson, 1993; Perini, 2009; Scerri, 2009). Relationships and interactions formed between actors define the system. This network of activities and interactions catalyse, adopt, adapt and promote the use of new technologies and innovations (Tigabu, 2017).

The process of interaction, as suggested by Lundvall and Johnson (2016), requires enhanced communication. Through the act of communication, knowledge is exchanged, and learning takes place to produce innovative products or processes. This is important for economic development because the circulation and utilisation of knowledge enables nations, regions, sectors and firms to collaborate and compete to advance and contribute to economic activity (Carayannis & Campbell, 2010; Castells, 1996; Gibbons et al., 1994; Kraak, 2007).

Interaction in the system is a collaborative effort; this means "any activity where two or more partners contribute … resources and know-how to agreed complimentary aims" (Dodgson, 1994, p. 285). While collaboration has many variants, generalised assumptions underpin the concept. First, the mutual benefit of working together, for example, cost and knowledge sharing. Second, dealing with economic uncertainty and shock. And, thirdly, it can provide flexibility and efficiencies (Dodgson, 1994; Schilling, 2015).

As is indicated earlier, in the main the majority of system of innovation literature and policy does not often explicitly cover or acknowledge the role of civil society in the innovation process (Douglas, 2019; Harsh et al., 2018; Schillo & Robinson, 2017). Therefore, this interpretation underpins the selection of the quadruple helix framework, which implicitly acknowledges the role of civil society in the innovation process. It was against this model that the effectiveness and collaborative nature of the South African forestry-products biorefinery innovation system was assessed (see Chapter 7).

4.2 Systems of innovation perspective

Systems of innovation can be defined as "networks of institutions within which innovations are generated, adapted, diffused and deployed" (Scerri, 2016b, p. 23). Systems of innovation discourse[22] , and therefore TIS, has its foundations in evolutionary and institutional economics (Edquist, 2005; Tigabu, 2017), and interactive learning (Lundvall, 2016). Geels' (2002; 2004) work on socio-technical system transitions has also been an influence on the theoretical

[22] Also sometimes referred to as a framework or approach, rather than a theory.

development of TIS thinking. He suggested that technological niches[23] provide an opportunity for radical novelty that challenge relatively stable regimes[24] (Coenen et al., 2017; Verspagen, 2007). Geels was influenced by Schumpeter's notion of creative destruction, which is the idea that capitalism is a process of destruction, and innovation is the creative basis upon which the rules of the norm are challenged (Galunic & Rodan, 1997; Reisman, 2004). Schumpeter suggested that innovation (particularly entrepreneurial) plays a significant role in the dynamics of an economy (Carayannis et al., 2017; Lundvall, 1992; Verspagen, 2007).

In the 1970s, authors such as Rosenberg and researchers at Sussex University further developed and explored the role innovation plays in an economy. They emphasised understanding the dynamics and consequences of innovation, and the role of science and technology in innovation (Malerba & Brusoni, 2007; Tigabu, 2017). The Sussex group stressed the need for institutional change and improvement of R&D capacity in developing countries to enhance technological and innovation advancements (Tigabu, 2017).

However, it was not until the 1980s that the assumptions of standard economics within innovation discourse were challenged. With systems of innovation thinking coming to the fore through the work of economists such as Nelson of Yale University's Institute for Social and Policy Studies, Freeman and Pavitt of the Science Policy Research Unit (SPRU) at Sussex University, Dosi of the Institute of Economics at the Scuola Superiore Sant'Anna, Pisa, and Soete of Maastricht University's School of Business and Economics in the late 1980s/early 1990s (Edquist, 2005; Lundvall, 2007a).[25] Their work explored most prominently national systems of innovation (NIS), high-technology sectors and regional comparisons with reference to how innovation is managed, work practices and engineering education. This work emanated from a pioneering collaboration between Freeman, Lundvall and Nelson while working on an International Federation of Institutes for Advanced Study project (Lundvall et al., 2009; Vertova, 2014).

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[23] "Technological niches" form the micro-level of an innovation system and refer to the "locus for radical innovations" (Geels, 2006, p. 171).

[24] "Socio-technical regimes" form the meso-level of an innovation system and refer to the "rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures" (Geels, 2006, p. 171; Rip & Kemp, 1998, p. 340).

[25] The institutions listed for each scholar are those they were based at during the period of citation.

It was only in the 1990s, and with the burgeoning use of innovation systems frameworks, that knowledge within an NIS began to gain prominence. This followed the publication of Gibbons et al.'s (1994) work *The new production of knowledge: The dynamics of science and research in contemporary societies* (Cavallini et al, 2016; Coenen et al, 2016). This publication coincided with publications by Lundvall, Nelson and the OECD on NISs, as well as the establishment of the Systems of Innovation Research Network in Canada by Edquist (Cooke et al., 1998; Edquist, 2005; Lundvall, 2007a). These activities began to legitimise systems of innovation discourse as the approach became more formalised, and discussions on theoretical and empirical research quality were held (Edquist, 2005). It was also at this time that attention was paid to those who provided education or developed the capacity of individuals working in a system (Edquist, 2005).

In terms of the theoretical underpinnings of systems of innovation thinking, Lundvall (2007a) explained that evolutionary economics provided the theoretical foundation. Evolutionists are interested in the process of change, and acknowledge the presence of technological and organisational learning and market selection as core to economic change (Cooke et al., 1998; Dosi, 2007). This contrasts with standard and neoclassical economics, which recognises innovation intervention as a necessity when there is market failure. Actors involved in an economy are considered rational and well-defined (Coenen et al., 2017; Lundvall, 2007a; Perini, 2009).

Evolutionists see innovation processes as cumulative. However, it is suggested that they do not acknowledge that these processes follow equal paths, and that innovation process outcomes are often uncertain (Cooke et al., 1998; Nelson, 2007; Scerri, 2009; Verspagen, 2007). An interest in the nature of change is core to evolutionary economics and systems of innovation discourse. As alluded to earlier, it is informed by the work of Schumpeter and how innovation and change can alter or disrupt the practice of an organisation or system (Bercovitz & Feldman, 2007; Metcalfe, 2007; Nelson, 2007). For example, this is witnessed in the work of Nelson and Winter (1982) (evolutionary economists). When exploring innovation, they "married an evolutionary theory of technological change with a behavioural theory of a firm" (Nelson, 2007, p. 31).

The core features of a system of innovation framework recognise the importance of actor collaboration (Bauer et al., 2018; European Commission, 2018; Ollikainen, 2014). Learning and competence are key elements and play the part of a differentiator (some would argue neglected) in standard economics. However, the central role of knowledge acquisition and diffusion has not always been at the forefront of the system of innovation perspective. The first iterations of the perspective tended to play down the importance of knowledge and learning. It focused on the double-helix model, which emphasised the relationship between academic institutions and industry (Carayannis et al., 2017; Nelson, 2007).

Lundvall placed particular importance on learning and competence: He stated that "to bring innovations, including science-based innovations to the market, organisation learning, industrial networks as well as employee participation and competence building are more important than ever" (Lundvall, 2007a, p. 2). This is supported by his contemporaries, Cooke et al. (1998), Nelson (1993) and Coenen et al. (2016, p. 3), who suggested "innovation processes are social learning processes". This is reflected in Evers' (2014) thesis on knowledge development and diffusion within a biorefinery TIS. He validated his use of the approach as it allowed for "a more sophisticated examination of knowledge development and diffusion" (Evers, 2014, p. 11).

In addition to the role of knowledge, Lundvall suggested that innovation systems are also about the ability of the actors within the system to absorb and use knowledge to develop and adopt innovations (Lundvall, 1992, 2007a; Tigabu, 2017).

This centrality of knowledge and learning in systems of innovation discourse is a critical component of the theory and this study. While discussed further in the following chapter, in essence, knowledge is seen as the "most fundamental resource in our contemporary economy" (Carayannis & Campbell, 2010; Lundvall & Johnson, 2016, p. 107), and learning is seen as a key dimension of "innovativeness" (Grønning & Fosstenløkken, 2015, p. 1).

As an innovation system can be influenced by many actors and factors, it is suggested that the knowledge within it is dynamic and forever changing. Learning is affected by shifting policy and the dominant socio-technical context within which it operates (Edquist, 2005; Metcalfe, 2007; Van Eijck & Romign, 2009). Taking complexity into consideration, Van Eijck and Romign (2009) argued that this is even more challenging when trying to implement radical innovations to overcome environmental, social and economic issues. They suggested this adds another dimension of complexity. The consideration of environmental and social elements is covered in this chapter under the discussion on a quintuple helix framework (see Section 4.2.2).

The scope of systems of innovation discourse is broad and diverse. It emerged into different applications that share the same foundations yet focus on different units. Thus, there are national, regional, sectoral, organisational and technological systems of innovation (Tigabu, 2017). Each of these derivatives provides a framework for understanding how actors, networks and institutions collaborate to develop innovations that enhance economic growth (Lundvall, 2007a; Uriona & Vaz, 2017). NIS is often the main sub-system described and studied, and is used widely in state innovation policy, as is the case in South Africa. NIS tends to describe and explain some of the main premises and elements of an innovation system at the national level and is often therefore the primary mega-perspective used for system of innovation sub-systems. For more granularity of understanding, regional, sectoral, organisational and technological frameworks emerged and can be used.

While NIS is widely referred to and used in state innovation policy (including South Africa [see (SA Department of Science and Technology, 2018c; Manzini, 2015; Paul et al., 2012]), it is the TIS application that is adopted in this study. The reason for its adoption is that it is the most "fit for purpose" (Scerri, 2016b, p. 31) and provided specific functions to assess the forestry-products biorefinery innovation system in a more prescriptive and heuristic dimension, particularly with respect to a given technology (Scerri, 2016b), aka biorefineries (see Chapter 3, Section 3.3.1 for the selection reason).

4.2.1 Technological innovation systems

TIS literature focuses on a specific technology or fields of technology. It uses a framework of functions to assess the dynamics of the system. These dynamics are the strengths, weaknesses, performance, structure and maturity of the system, and the development and use of the technology. Since its first use in the early 1990s, TIS has had various iterations as a response to both negative and positive critiques from the scholarly community. For example, while the framework of functions is the most recognised dimension of TIS, further iterations have embedded these among other dimensions (dynamics), such as structural components, policy issues, inducement and blocking mechanisms, as well as the heuristic process to assess the TIS itself (Bergek et al, 2008).

The first authors to distinguish TIS from other system of innovation applications were Carlsson and Stankiewicz (1991). They argued that technological systems are not determined by geographical boundaries, but by interactive networks operating in a set of infrastructures to generate, diffuse and use technology.

A key component of the interaction is the generation and transference of knowledge (Carlsson et al., 2002). This encompasses both the development of technology and the capacity and competence of the network to identify, absorb, adapt and use new technology (Tigabu, 2017). This aligns with Lundvall (1992, 2007a) and Lundvall et al's (2002) recognition of actor competency and capacity to use knowledge to develop and adopt innovations.

The development of the first list of TIS functions was proposed by Johnson (1998). He investigated how previous systems of innovation studies assessed what occurred within a system. According to Bergek et al. (2008), a similar list was proposed by Rickne (2000) for an empirical study on the biomaterials sector. Drawing on the work of Johnson (1998) and Rickne (2000), as well as political science, socio-technical and organisational literature, Bergek et al. (2008) progressed the discourse. They presented a list of seven functions to develop a "scheme of analysis" and practical guidelines for policymakers to identify issues and goals (Bergek et al., 2008, p. 408). This element, they suggested, was lacking in previous empirical innovation system studies. Around this time, Hekkert et al. (2007) also adopted a set of functions. Other authors subsequently adapted this list of functions (such as Hekkert & Negro, 2009; Uriona & Vaz, 2017; and Walz et al., 2016).

The functions developed and adapted by the above-cited authors can be categorised as follows: (a) knowledge generation and diffusion through networks; (b) influence of the direction of research; (c) entrepreneurial activities and experimentation; (d) market formation; (e) legitimisation of technologies; and (f) resource mobilisation. Each function theme carries a set of indicators for assessing the dynamics of a TIS. These functions are applied in Chapter 7, to assess the maturity, functioning and performance of the South African forestry-products biorefinery innovation system. The core themes (or functions) and their indicators are given below.

- *Knowledge generation and diffusion through networks* are usually separate functions. Knowledge generation encompasses learning-by-searching or doing. The unit of analysis used is, for example, the number of research and development projects, investment and patents associated with a technology (Hekkert et al., 2007; Uriona & Vaz, 2017).
- The *knowledge diffusion* function assesses the level of information exchange within the TIS and how it is diffused between actors in the system. This is determined by

mapping, for example, the number of conferences held on the technological topic and the network size (Coenen, 2010; Hekkert et al., 2007; Uriona & Vaz, 2017).

- *Influence of direction of research* refers to understanding what is driving, and the requirements of, the technological and R&D research. Mechanisms for assessing this function include, for example, identifying the number of articles published and the focus of research undertaken on the technology (Hekkert et al., 2007; Uriona & Vaz, 2017; Walz et al., 2016).
- *Entrepreneurial activities and experimentation* cover the level of activity of new business into the technological market, including established entities seeking to diversify their business (Hekkert et al., 2007; Uriona & Vaz, 2017). It may encapsulate technological diversity, level of experimentation and creation of new opportunities (Bergek et al., 2008; Coenen, 2010; Hekkert & Negro, 2009; Markard, 2018; Walz et al., 2016).
- *Market formation* investigates how space for new technology markets is encouraged and enabled. It also includes the demand for market development, such as project pilots (Bergek et al., 2010; Coenen, 2010; Hekkert et al., 2007; Markard, 2018; Negro, 2007; Uriona & Vaz, 2017). Indicators can include the number of niche markets, new technology tax incentives or standards introduced (Hekkert et al., 2007; Uriona & Vaz, 2017).
- *Legitimisation of technologies* encapsulates the level to which actors in a TIS are willing to accept new entrants (Hekkert et al., 2007; Uriona & Vaz, 2017), counter-resistance and provide political support (Negro, 2007; Walz et al., 2016). This may be formulated through a supportive regulatory environment, policy and goals (Bergek et al., 2008; Coenen, 2010; Hellsmark et al., 2016).
- *Resource mobilisation* encompasses both financial and human capital supply to assess the availability of resources, ease of access and speed of redistribution into the system (Bergek et al., 2008; Coenen, 2010; Hekkert et al., 2007; Negro, 2007; Uriona & Vaz, 2017). Human competence and absorptive capacity, as mentioned by Lundvall (1992) and Negro (2007) would also be recognised within this function.

The TIS literature acknowledges that market forces alone cannot be relied on for a radical shift in innovation to occur to transition towards a more sustainable future. Authors argued that active support and new innovation policy is required (Markard & Truffer, 2008; Weber & Rohracher, 2012). As such, the TIS framework is widely used in bio- or green-economy TIS studies, with an emphasis on technologies that will enable a significant transformative shift (Markard & Truffer, 2008). By way of example, technologies covered included: biorefineries and materials (see Bauer et al., 2017; Coenen, 2010; Evers, 2014; Rickne, 2000; Söderholm et al., 2019), electric vehicles (see Budde & Weber, 2010), fuel cells (see Musiolik, 2012), renewable energy (solar, wind) (see Hu, 2017; Kriechbaum et al., 2018; Reichardt et al., 2017; Rennkamp & Perrot, 2016; Tigabu, 2017; Walwyn, 2016), and smart grids (see Planko et al., 2017).

TIS and developing economies

Given the complexities of innovation systems, the diversity of actors and socio-economic contexts, the appropriateness of TIS in developing economies is worthy of discussion (Kuhlmann & Rip, 2014, 2018; Walz et al., 2016). Most TIS studies are undertaken in advanced economies, notably Scandinavia, the Netherlands and Germany (for example, Bergek et al., 2008; Hekkert et al., 2007; Markard, 2018; Uriona & Vaz, 2017). This reflects these countries eco-political focus on transitioning towards a bioeconomy[26] and their need for eco-innovation solutions to do so (Bauer et al., 2018; European Commission, 2018). With the exception of Douglas (2019), Rennkamp and Perrot (2016), Van Heyningen (2016) and Walwyn (2016), few TIS studies reference or are located in South Africa. However, authors such as Egbetokun et al. (2017) and Tigabu (2017), articulated the need for the adoption of TIS in developing economies to catalyse technological and transformative change. The TIS framework has been criticised for its lack of reference to geographical context (Binz et al., 2014; Coenen et al., 2016; Netshitenzhe, 2016), societal benefit, and inclusion of marginalised groups in innovation development (Douglas, 2019), which would therefore capture some of the notable characteristics of developing economies. It is therefore argued that TIS should consider these (Altenburg, 2009; Botha et al., 2016; Cozzens & Kaplinsky, 2009; Douglas, 2019; Manzini, 2015). In addition, Arocena and Sutz (2000) suggested that, in developing economies, innovation system discourse in the broader sense should also aim to build technical capabilities, promote learning and develop strategies to create systems of innovation. These considerations are echoed in the work of Kuhlmann and Rip (2018, pg. 448). They explored the need for science, technology and innovation policy to respond to and address the "grand challenges*"* our world currently faces, for example, climate change, sustainable consumption, poverty,

[26] According to the European Commission's (2018, p. 50) updated bioeconomy strategy, the circular- and bio-economy nexus "intersect in their common aim to add value to biological waste and residues".

inequality, peace and justice. All of these are particularly fitting to the everyday challenges faced by South Africa.

In terms of context, Bergek et al. (2015) responded to the criticism of lacking reference to geographical context and societal benefit, by expanding on their initial functions. These now include four types of “context structure”: technological, sectoral, geographical and political (ibid., p. 51). This would suggest the TIS framework is maturing in recognition of criticism, and therefore becoming more conducive to developing economy application.

In addition to this, for example, the Global Network for Economics of Learning, Innovation, and Competence Building Systems (Globelics) has, since the mid-2000s, emphasised scholarly work on innovation and economic development in developing economy contexts (for example, Chaminade & Padilla-Pérez, 2017; Chaminade & Vang, 2008; Lundvall et al., 2009). This has been through, for example, hosting conferences in developing countries, and establishing regional networks in Africa, Asia and Latin America. This has enabled developing country researchers to present their papers in context relevant geographies (Globelics, 2020).

In addition, and as noted by Lundvall et al. (2009), the NIS framework is increasingly being used by developing economies to set and frame innovation policy. South Africa is a case in point, with NIS formally entering policy discourse in 1996, with the publication of the *White paper on science and technology* (Netshitenzhe, 2016). Ten-years on from this publication, *The emergence of systems of innovation in South(ern) Africa: Long histories and contemporary debates* (Scerri, 2016a) was published. This collection of essays by African authors explores the “theoretical and analytical contribution to the understanding of the complex interactions between innovation and development and how developing countries are being inserted into the present financial-dominated globalisation process” (Cassiolato, 2016, inside cover). One of the dimensions covered in the publication is the integration of the informal economy into South Africa’s national innovation system (Kraemer-Mbula, 2016). This alludes to (but not explicitly) civil society as an actor within systems of innovation discourse. As noted earlier, Douglas (2019), in her thesis *Towards inclusive and responsible technological innovation systems*, critiqued the general neglect of this component of society, in particular, the marginalised poor in TIS discourse.

It is this element, civil society (in the broadest sense), which this study argues should be requisite in a collaborative and effective South African forestry-products biorefinery innovation system. While studies suggest that civil society's contribution to science or innovation is often seen as irrational or ignorant (Bäckstrand, 2003; Irwin, 1995; Ottinger, 2010), it can play a significant role in contributing to enhanced collaborative innovation development. It is on this basis that the quadruple helix framework is considered.

4.2.2 Quadruple helix framework

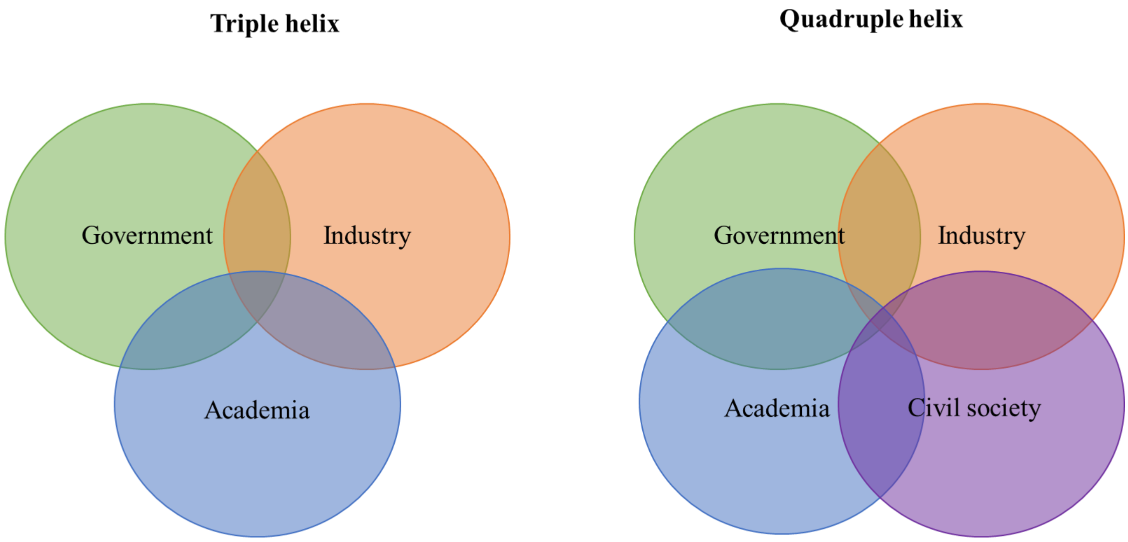
The quadruple helix framework, for this study, is interpreted as a conceptual system of innovation approach, and not as an alternative to the system of innovation perspective. The notion of it being an alternative framework is supported by authors such as Etzkowitz and Leydesdorff (see 2000) who suggest the helix approach is clearly distinct, as alluded to in their paper *The dynamics of innovation: from National Systems and 'Mode 2' to a triple-helix of university-industry-government relations.* As with this study's positioning of the quadruple-helix as a system of innovation framework – scholar's such as Lundvall et al (2009) are also comfortable with seeing the various helix models (triple, quadruple, quintuple, n-tuple) as sub-systems of the broader system of innovation perspective.

The quadruple helix framework was conceptualised by Carayannis (School of Business, George Washington University) and Campbell (Institute of Science Communication and Higher Education Research, Alpen-Adria-Universität, Austria). They established the concept in the mid-2000s (Carayannis & Campbell, 2009) as a critique of systems of innovation discourse (Campbell et al., 2015; Carayannis & Campbell, 2011; Grundel, 2017). Campbell et al. (2015) found the discourse too undemocratic and narrow due to the under representation of civil society as an actor in the innovation process. The quadruple helix framework recognises four actor groups in an innovation system: government, industry, academia and civil society (Cavallini et al., 2016a; Grundel, 2017; Hasche et al., 2019; Leydesdorff, 2012). This set of actors forms an ecosystem of innovation (Afonso et al., 2012) within which knowledge generation is perceived to be human-centred and democratic (Carayannis & Campbell, 2012, 2014).

This differs from the triple helix framework developed by Etzkowitz and Leydesdorff (1995), which frames innovation in an economy as having a trilateral network of actors – government, industry and academia (see Figure 3) (Etzkowitz & Leydesdorff, 2000; Ranga & Etzkowitz, 2013; Strand et al., 2015). The intention of the triple helix was to distinguish the roles of science, the market, and private and public ownership in the context of knowledge and technological commercialisation through university diffusion (Leydesdorff & Etzkowitz, 1996; Pant, 2019).

While recognising a distinction of roles, the triple helix model acknowledges the need for actors to collaborate strategically to identify and mitigate cross-cutting issues that no actor could resolve on their own (Kimatu, 2016).

Figure 3: Networks of actors in the triple helix and quadruple helix frameworks[27]



The quadruple helix framework, on the other hand, suggests that technological interventions generated under the triple helix model have not always fulfilled their long-term potential and growth due to, amongst others, not meeting societal needs. This they argue is because society is not explicitly recognised as an active role player in the innovation process (Khan & Al-Ansari, 2005; Schütz et al., 2019; Steenkamp, 2019). Therefore, supporters of the quadruple helix model suggest that, for innovation to prove effective and beneficial, civil society needs to be an explicit role player in the innovation system, and therefore a fourth helix (see Campbell et al., 2015; Carayannis et al., 2017; Carayannis & Campbell, 2010; Khan & Al-Ansari, 2005; Kimatu, 2016; Liljemark, 2005). While it is acknowledged that within the TIS literature civil society may have provision made for it in the form of advocacy coalitions (see Bergek et al., 2008), their inclusion as an actor group is not always explicit. As such, it has been suggested that a transformation of the triple helix model is required (Pant, 2019) so that civil society can have a more prominent and acknowledged voice (Bornmann, 2013; Carayannis & Campbell, 2009; Kimatu, 2016; Martin, 2011). This can be done:

[27] Developed by the author and informed by: Carayannis & Campbell, 2010; Etzkowitz & Leydesdorff, 1995; Leydesdorff & Ivanova, 2016; Pant, 2019.

- by legitimising innovations and demanding respect (Benhabib, 1996; Brabham, 2012; Gutmann, 2004; Lövbrand et al., 2011; Schütz et al., 2019; Steenkamp, 2019),
- by ensuring positive impact and benefit via sustainable solutions (Chesbrough, 2006; Hippel, 1988; Park, 2014; Schraudner & Wehking, 2012), or
- by defining or demanding innovations via customers and users (Carayannis & Campbell, 2009; Caruso, 2018; Geels & Schot, 2007; Jørgensen et al., 2009; Schütz et al., 2019; Steenkamp, 2019).

Why civil society should be considered a significant actor in the TIS

Civil society as a concept gained popularity in the 1980s as a manifestation of the need by citizens to form collective action to articulate local interests (Abernathy & Clark, 1984; Cooper, 2018; VanDyck, 2017; World Economic Forum [WEF], 2013; Williams, 2018) and to respond to technological, market and political opportunities and pressures (WEF, 2013). While the term is often presented in the singular (Institute of the Future [IftF], 2018), in reality civil society is a heterogenous and diverse “ecosystem of individuals, communities and organisations” (Ahrweiler et al., 2019; WEF, 2013, p. 6; Williams, 2018). It represents “cross-cutting trans-sectoral actor-networks and hybrid organisations” (Evers, 2013, p. 161). Civil society can refer to issue-driven non-government organisations (NGO), culture-based public entities, the media, trade unions, community groups, intermediaries and users of an innovation (Carayannis et al., 2017; Cavallini et al., 2016; Ivanova, 2014; Jezard, 2018; Nugroho, 2011).

In essence, civil society organisations or collectives can be defined by two key features: first, they are independent from the state (hence the term “non-government organisation”[NGO]); and secondly, they are in the main not for profit (Ahrweiler et al., 2019; Hutter & O'Mahony, 2004; Nugroho, 2011). They can range in size, organisational structure and geographical representation (African Development Bank, 2012; Cooper, 2018; WEF, 2013; Williams, 2018). In South Africa, it is estimated that more than 100 000 NGOs operate in the country (Matthews, 2017). They respond to and express a variety of political, social, economic and environmental interests, aspirations and concerns (African Development Bank, 2012; Cooper, 2018).

In the quadruple helix literature, civil society is represented in two ways: first, government, industry and academia operate as a whole or as part of civil society (Höglund & Linton, 2018; Schütz et al., 2019); or second, civil society is a fourth helix or distinct actor group (see Carayannis & Campbell, 2010; Schütz et al., 2019). Civil society can take on a diversity of roles, and therefore agency, within a quadruple helix system of innovation. Roles include those of service provider, advocate and campaigner, society watchdog, activist, builders of capacity and relationships, as well as experts and idea generators (Ahrweiler et al., 2019; Cooper, 2018; Geels & Urry, 2014; Penna & Geels, 2015; Veress, 2017; WEF, 2013). Therefore, it is argued that the role of civil society is as genuine and equitable as government, industry and academia in innovation processes. This was succinctly captured by Ingrid Smith, the former Secretary General of CIVICUS[28], who commented in an interview with WEF, "civil society is consistently trusted far more than government, business and the media at a time when trust is by far the most valuable currency" (WEF, 2013, p. 16).

It is argued that the inclusion of civil society in the innovation process allows for more opportunities to address societal challenges in a shared space. This speaks to Kuhlmann and Rip's (2018, pg. 448) *grand challenges*. It allows for new approaches for collaboration and partnership (Pant, 2019; WEF, 2013). To be more specific, authors have argued that the inclusion of civil society brings social, cultural, ethical and moral values to the fore in the innovation process (Einsiedel, 2002; Hasche et al., 2019; Nordberg, 2015; Pant, 2019; Rip, 1995; Schot, 2001).

While the quadruple helix perspective argues for the strategic integration of civil society in the innovation process, this does not necessarily mean that such an integration will occur. It also does not suggest that if civil society is included, this will be effective, or their role adequately acknowledged. As such, authors argue that, for innovation to be responsible and include civil society, six areas need to be considered or enhanced:

1. the design of inclusive and transformational innovation spaces to enable participation in innovation development and research (Biggs & Smith, 1998; Whyte, 1991)
2. the institutionalisation of civil society engagement which enables participation as activism, citizen science and users of innovations (Hounkonnou et al., 2012; Leydesdorff & Ward, 2005)
3. improvement in the levels of trust between civil society, government and business (Muok & Kingiri, 2015)

[28] CIVICUS is an alliance of civil society organisations and activists engaged in confronting and overcoming the challenges facing society through strengthening civil society action globally (CIVICUS, 2018).

4. increased transparency and recognition of civil society accountability. This should represent the needs or issues of those they represent, rather than their funders. This is a critique levelled at civil society organisations (see Banks et al., 2015; S. Drimie, personal communication, 6 February 2020; Matthews, 2017; Shivji, 2007)
5. innovation policies that address poverty, inequality, social inclusion and sustainability, particularly in Africa (Kuhlmann & Rip, 2014, 2016, 2018; Muok & Kingiri, 2015).

While this exploration of the concept of civil society and the value it brings justifies its centrality in this study, it means that civil society should be recognised as having many guises, characteristics and roles. In addition, as highlighted above, there are many challenges to consider when including civil society in the innovation process. However, numerous benefits could be realised by including civil society. For example, conflicts could be minimised, and innovations could be adopted to respond to economic, social, political and environmental challenges.

Sustainability and the quintuple helix

A relatively recent evolution is the formulation of the quintuple helix framework, which sets the quadruple helix approach within a sustainability context (Carayannis et al., 2012; Carayannis et al., 2017). This is pertinent to this study, as biorefineries are a technical innovation response to the need for sustainable practices. This echoes the work of institutions such as CIRCLE at Lund University, Sweden. They state the aim of their work is "to understand and explain how innovation can contribute to a good society and tackle societal challenges like economic crises, climate change or increased globalisation of economic activities" (CIRCLE, 2017, para. 2). The environment (or nature) becomes an essential, equitable and central component of knowledge production and innovation (Carayannis et al., 2012; Grundel, 2017; Ivanova, 2014; Kotilainen et al., 2016).

Emphasising sustainability (quintuple helix) and civil society (quadruple helix) complements the view of Lemille, a thought leader of circular economy[29] in South Africa. Lemille maintained that, while the circular economy concept was laudable, it lacked adequate recognition of the social dimension and ability to mitigate social inequalities (Lemille, 2016). Much like the core

[29] The *circular economy* is defined as "restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. [It] seeks to ultimately decouple global economic development from finite resource consumption" (Ellen MacArthur Foundation, 2015, p. 1).

constructs of system of innovation theory, the role of actors is critical in the innovation process. Lemille saw the same for society in circular economy discourse. He noted that “humans are the key to the complexities we face today: on the one hand, a wrongly designed relationship with our environment, on the other hand, a source of endless energies to fix our economic model while thriving” (Lemille, 2019, para. 17). It is on this premise that this study interrogates the role of change agents in the South African forestry-products biorefinery innovation system (see Chapter 9).

4.3 Conclusion

This chapter explored the theoretical evolution and underpinnings of the broader systems of innovation theory, with the selection of and explicit focus on TIS. It unpacked the key principles of innovation realised through relationships, interactions and knowledge sharing. Drawing on these foundations, the TIS framework was presented as an appropriate approach to understanding the dynamics of the South African forestry-products biorefinery innovation system. The reason for using the TIS was twofold: first, it provides a framework of functions to assess the dynamics of a specific technology; and second, it is widely used for assessing eco-innovation systems, both of which reasons speak to the topic of this study. While the TIS framework is appropriate for this study, they do not – for the purposes of this study, adequately and explicitly highlight and/or recognise the role of civil society as actor. For this reason, the quadruple helix framework was explored. This framework explicitly acknowledges and emphasises the role of civil society as an equitable actor in the innovation process. However, civil society should not be assumed to be a homogenous entity. The inclusion of civil society within an innovation process should be cognisant of its variability. It should ensure adequate input from civil society representatives from the onset to develop trust and an effective platform for collaboration.

By understanding the conceptual frameworks of TIS and the quadruple helix, it was possible to build a complementary theoretical platform for this study, notably the theoretical conceptualisation of an ideal effective and collaborative TIS set within a stainability context.

One of the core elements of all systems of innovation framings is the importance of knowledge, knowledge exchange and the competencies of those in the network. This enables market-orientated innovation, maintains competitive advantage and economic survival. Given the focus of this study on the knowledge network associated with the South African forestry-products biorefinery innovation system, the theoretical context of knowledge and innovation is covered in the next chapter.

Chapter 5:
Knowledge production and diffusion in innovation knowledge networks

Knowledge and learning are central to systems of innovation discourse, as is acknowledging that through collective interaction between actors, innovation as an advantage can be realised. As such learning becomes a strategic process in advancing the economy and an innovation, they become inseparable (Kahin, 2006; Lundvall & Johnson, 2016). This perspective provides an alternative to “current national strategies [that] focus on fiscal balance and cost competitiveness” (Lundvall, 2016a, p. 4) as drivers of innovation. As such, knowledge and learning become prerequisites for competitive advantage. This is either through the transferal and sharing of knowledge or through holding onto knowledge to expedite innovation and enhance innovative performance (Kraak, 2007; Lundvall et al., 2002; Parveen et al., 2016; Tallman et al., 2004).

While innovation systems literature tends to focus on knowledge production, particularly through interaction and learning, it tends to lack clarity on the network of actors producing and exchanging knowledge. It also tends to neglect the dynamics of knowledge creation and flow within the network. These limitations are pivotal for this study. This is because a critical hypothesis of this study is that innovation arises through a social process, whereby “knowledgeable people share knowledge” (Nordqvist & Frishammar, 2018, p. 4).

To address this limitation, this chapter seeks to interrogate the broader innovation system literature to ascertain how knowledge and learning is conceptualised and framed. While the literature refers to the importance of knowledge sharing and learning through interactive actor relationships, there is no explanation of how to analyse the knowledge dynamics of a TIS. For this purpose, this chapter contributes to TIS literature by suggesting that knowledge network analysis, through a social capital lens, is an appropriate framework for conceptualising the exchange and flow of knowledge in a TIS.

Section 5.3 presents a conceptual framing of knowledge network analysis. It looks, in particular, at knowledge network analysis as a mechanism for empirical reflection on the network of actors and individuals interacting and exchanging knowledge in the system. Within this discussion, inhibitors to learning and knowledge transfer in a network are explored, such as the importance of trust and knowledge lock-in.

5.1 Knowledge and the economy

Numerous authors writing on the modern economy argue that our current knowledge-based economy is centred around knowledge and no longer around factors of labour, land and capital (see Brinkley, 2006; Cooke, 2005; Dolfsma & Soete, 2006; Foray, 2006; Guile, 2010; Kraak, 2007; Lundvall & Johnson, 2016; Sorlin & Vessuri, 2007). It has been suggested that the concept of a knowledge economy was first introduced in the early 1960s, either by Drucker (1993) or Machlup (1972) (Cooke, 2005). While there are variations of the knowledge economy concept, Sokol (2005, p. 216) suggested that it is generally accepted (see Castells, 1996; Cooke, 2002; Giddens, 2000; Leadbeater, 2000) that "society and economy are being transformed into some sort of information society or knowledge-driven-economy." In this capacity, knowledge is referred to as an enabler of production, diffusion and application to stimulate and sustain human production, wealth and economic activities (Carayannis et al., 2016; Guile, 2010; Osborne, 1998). It is therefore argued that, for example, a business to compete successfully in the knowledge economy, it needs to be effective in acquiring, sharing and producing knowledge. Knowledge is considered a key organisational asset and central to contemporary productive capital (Du Toit, 2014; Grulke, 2000; Kraak, 2007; Muller & Subotzky, 2001; Van Reijsen, 2014). Consequently, it is argued that those who gather and produce knowledge also control it, thereby providing a power dynamic within a system (Kincheloe, 2008; Skordoulis, 2016; Sorlin & Vessuri, 2007). This sentiment builds on Foucault's (1991) understanding of how knowledge functions as power. He suggested scientists and policymakers should identify "the sayable, the conservable, the memorable, the retainable, the valuable, the institutionalisable and the controllable" (ibid., p. 59). This is echoed by Luke (1989), who investigated how the academic production of knowledge sought to socialise, politicise and stabilise society.

Given this overview of the knowledge economy, it should be noted that the overview's purpose was not to offer a critique of the concept. Its purpose was merely to provide an overarching introduction to set the context of knowledge in this study. For useful critiques of the concept, see Livingstone and Guile's (2012) publication *The knowledge economy and lifelong learning: A critical reader.*

5.2 Centrality of knowledge and learning in innovation system discourse

Knowledge and learning in the systems of innovation literature are argued as being pivotal to the innovation process and variant frameworks' discourse (Cooke et al., 1998; Cooke et al., 2007; Lundvall et al., 2002; Lundvall & Lorenz, 2007; Metcalfe, 2007; Perini, 2009). Lundvall (1985, 1988) and colleagues from Åalborg University in Denmark, publishing in the 1980s, were the first economists to offer this perspective. They explored the importance of knowledge and learning in relation to national systems of innovation. Their assumptions were twofold. The first assumption was that knowledge is the most fundamental resource in a contemporary economy and that learning is therefore the most important process. Their second assumption was that learning is fundamentally an interactive and socially embedded process (Lundvall, 2016b). As such, the institutional and cultural context of the learning process cannot be neglected. In this regard, concepts such as "learning-by-combining" and "learning-by-interacting" entered the literature (Grønning & Fosstenløkken, 2015, p. 5). This can be compared to more traditional or neo-classical economists who tended to view knowledge production and learning in the broadest sense, either as a means of accessing information or as a "black box" (Verspagen, 2007, p. 44), in which growth models assume learning takes place through doing or experiencing.

Lundvall and Johnson (1994) were amongst the first to deconstruct and comment on the critical role of knowledge and learning as process in innovation systems. By doing so, they contributed to the general theory of innovation by way of introducing the learning economy concept. In their paper on the learning economy, they interrogated the implications of their views of knowledge and learning for economic theory and market discourse (Lundvall & Johnson, 1994). Through doing so, they attempted to set out a conceptual framework for centralising knowledge and learning in economic change analysis.

By the late 1990s and early 2000s, the notion of knowledge and learning as central to the innovation process was being explored from a regional innovation perspective by authors such as Lawson and Lorenz (1999) and Asheim and Coenen (2005), and from a sectoral perspective by Malerba (2002). During this period, Lundvall et al. (2002) began to emphasise the importance of learning capability and competency to expedite the rate of economic performance through innovation. The reason provided for this development was that system of innovation discourse had not adequately emphasised "the subsystem related to human resource development” (Evers, 2014; Lundvall et al., 2002, p. 224). In the case of the TIS approach, proponents such as Carlsson et al. (2002) and Coenen and Lopez (2010) suggested their interpretation was too simplistic and ignored the subtleties of knowledge production.

It is also at this point that different paradigms of knowledge production were articulated in innovation system discourse. This articulation enabled an understanding of how knowledge is created and shared in national and regional systems, and by business (Fischer, 2001; Fischer & Fröhlich, 2001; Lundvall et al., 2002; Simmie, 2003). The knowledge paradigms predominantly recognised were codified and tacit.

5.2.1 Evolution of knowledge paradigm discourse

While the debates on knowledge production appear fragmented (Guile, 2010), two distinctions were commonly recognised (Bortagaray, 2004; Hessels & Van Lente, 2010): the first is often referred to as Mode 1, a more traditional (codified) manner; and the second is referred to as Mode 2, learning through doing (tacit) (Witt & Zellner, 2007). The latter is central to systems of innovation discourse (Lundvall & Lorenz, 2007), and expanded on in this section. Drawing on various literature, an overview of the distinguishing features of these two paradigms is provided in Table 9.

Table 9: Features of codified and tacit knowledge[30]

Knowledge paradigm	Codified	Tacit
Alternate labels	**Mode 1, traditional, formal, decontextualised, theoretical, orthodox, disciplinary, explicit, know-why**	**Mode 2, applied, problem-solving, implicit, strategic, on-the-job, know-how, know-what**
Features	− Problems defined by the academic community − Disciplinary knowledge − Homogeneity: hierarchical and stable − Research as objective − Theoretical and reductionist − Traditional, formal and orthodox − Exclusive and superior − University-led	− Knowledge produced in the context of application (contextualised science) − Transdisciplinary and joint knowledge production − Heterogeneous, diverse, transient and flexible − Research as reflexive and dialogical − Applied or on-the-job knowledge

[30] Derived from: Bortagaray, 2004; Bresnen & Burrell, 2013; Cavallini et al., 2016; Garud, 1997; Gibbons, 2000; Linder et al., 2003; Muller, 2012; Muller & Subotzky, 2001; Skordoulis, 2016; Winberg, 2006; Witt & Zellner, 2007.

Codified knowledge production is predominantly produced through the written word, such as journal articles, books and theses, patents, and orally via lectures and conferences. It is also generated in laboratories through which, Gibbons (2000) argued, the discipline of logic is justified, and societal knowledge excluded yet often drawn on (Bresnen & Burrell, 2013; Muller, 2012).

In their work *The new production of knowledge: The dynamics of science and research in contemporary societies*, Gibbons et al. (1994) formally distinguished the two disciplines of knowledge production in the context of suggesting a shift of dominance from codified to tacit (Mode 2). The latter was considered a new knowledge production paradigm (Gibbons, 1998; Gibbons et al., 1994; Hessels & Van Lente, 2010).

This suggests a transitioning of focus from codified to tacit knowledge production. However, authors such as Guile (2003, 2010) maintained the key issue in this debate was the rapid rate at which tacit knowledge was emerging and increasing in contemporary learning theory, particularly as the process of globalisation accelerated (Reich, 1992). Consequently, Guile argued that policy makers needed to adopt a more "reflexive" (Guile, 2003, p. 87) approach to learning to respond to an ever-increasing set of problems that no one mode of knowledge production could provide[31].

With an increased interest in tacit knowledge, the role of individuals and their competencies and capabilities to share and absorb knowledge became increasingly valued in an environment that was fast-paced and required flexibility to respond to a changing and competitive market (Gamble, 2004; Lundvall, 2007a; Sabel, 1995). It is this sharing of knowledge and learning-by-doing that has become a key feature of systems of innovation approaches (Jensen et al., 2007; Lundvall, 2007a, 2016a; Lundvall & Johnson, 1994, 2016; Witt & Zellner, 2007).

To distinguish more clearly between codified and tacit knowledge, Johnson et al. (2002, p. 249) presented four types of knowledge: "know-why", "know-what", "know-how" and "know-who". They were applied to both the organisation and individual level (Cowan et al., 1999). These categories correspond with the earlier work of Garud (1997), who drew on numerous fields of literature to argue for three of the distinctions identified by Johnson et al. (2002). *Know-why* is the understanding of the principles and laws underlying phenomena and functions

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[31] For a more in-depth commentary on this debate, Guile's (2003) paper *From "credentialism" to the "practice of learning": Reconceptualising learning in the knowledge economy* is excellent.

of a system through the process of study (Garud, 1997). While *know-why* is mostly codified, it can also be generated from individual skills (Johnson et al., 2002). *Know-what* is created through interaction and feedback between knowledge generators and users (Garud, 1997) or, as defined by Johnson et al. (2002), as the "facts" (which can be codified). *Know-how* is generated through the process of doing and learning how to perform an activity overtime (Garud, 1997) by drawing on skills, knowledge and experience (Johnson et al., 2002; Polanyi, 1962). Examples of know-how and know-why in praxis include duplicating and imitating what is seen, or assimilating research into practice (Rivera Vargas, 2011). Know-who, Johnson et al. (2002) argued, is important because knowledge is a composite asset of numerous sources of knowledge so knowing who holds information or knows what to do becomes imperative (Johnson et al., 2002). It is this knowing-who that alludes to a central theme of this study, that of the leverage professional. These are the individuals in the South African forestry-products biorefinery innovation system who have the agency for transformative change. This is explored further in Chapters 6 and 9.

By the late 2000s, Johnson, Lorenz and Lundvall, with their colleague, Jensen, advanced their discussion on forms of knowledge and modes of innovation (Jensen et al., 2007). They did so by introducing the concepts of STI (science, technology and innovation), and DUI (doing, using and interacting) modes of innovation. They drew on their previous work on know-why, know-what, know-how and know-who (Johnson et al., 2002). STI is associated with access to predominantly global codified knowledge (unless held in inaccessible forms, such as patents). It acknowledges that codified knowledge still leads to radical innovations through formal R&D. DUI on the other hand is associated with knowing-how and who. It is in the main localised tacit knowledge (Jensen et al., 2007). They suggest that both modes can function in parallel. However, they caution against the dominance of one form over the other, particularly in innovation policy (which aligns with Guile [2003, 2010]).

These two modes of innovation knowledge are referred to in the context of human, organisational and technical "absorptive capacity" (Jensen et al., 2004, p. 3) in an innovation system. This is similarly referred to as "core competencies" and "dynamic capabilities" (Borrás & Edquist, 2013). This absorptive capacity refers to the availability of skills, expertise and infrastructure to assess the potential of an innovation, as well as to the ability to enable learning, and exchange of knowledge at the individual and organisational level (UNCTAD, 2019). The concept was first introduced by Cohen and Levinthal (1990) in reference to the strengthening of science-based knowledge for innovation R&D. It also links to the notion of social capacity

(Jensen et al., 2004), and therefore the social capital of an innovation system's knowledge network (see Section 5.3).

Jensen et al.'s (2004) work, which builds on Cohen and Levinthal (1990), focuses on absorptive capacity in developing economies, in particular, the implications of transferring innovation from advanced to developing economies. While they recognised that a "copy and paste" approach would not be appropriate, they presupposed that, if a representative of a "private firm or a development aid organisation, know[s] something about the context in which the knowledge has to function and about the character of the context dependency, he (*sic*) will have better opportunities to support the necessary assimilation" (Jensen et al., 2004, p. 3). While this recognition can be commended, it speaks directly to contemporary African discourse on the recognition of in-country capacity and capability. It is not the purpose of this study to interrogate this further[32], but to raise it as a matter of concern in terms of capacity and competency in developing economies and source of interventions and/or innovations.

However, that aside, what is useful from the perspective of this study, is the significance of capabilities required to implement an effective and collaborative forestry-products biorefinery innovation system. "Capabilities" refers to an accumulation of knowledge and learning. This provides an individual, organisation or country with the ability or capacity to function or perform a task (Mncwango, 2013; Panda & Ramanathan, 1996; Sato & Fujita, 2009). "Competencies", on the other hand, are defined as a combination of knowledge, experience, skills, capabilities and attitudes. They contribute to an individual's performance (Garavan & McGuire, 2001; Gorsline, 1996; UN-L, 2020). Core competencies can include accountability, adaptability, communication, critical thinking and problem solving, inclusiveness, leadership, teamwork and work ethics (NACE, 2020; UN-L, 2020). Exploring this further in their paper on competence building and innovation policy, Borrás and Edquist (2013) distinguished between individual and organisation competencies. They note that competence is held by an individual or within an organisation. "Competence building" refers to the exchange or flow of competencies. This is particularly useful for this study in two ways: first, it refers to the competencies and skills of the individual (aka the leverage professional); second, it refers to competence building (aka knowledge transfer within a knowledge network). Building competency is also an element of human resource mobilisation, a function in the TIS framework

[32] For well-articulated discussions on this topic, see Awori et al., 2016; Melber 2015; Oelofsen 2015.

(see Section 5.2.2 below). It is these elements that are explored further with regard to knowledge networks and leverage professionals in the analytical Chapters 8 and 9 respectively.

Moving on, contemporary innovation and economic development discourse has begun to reflect on the contribution the literature and authors have made to the learning economy and innovation. In his book *The learning economy and the economics of hope*, Lundvall (2016c) reflected on the evolution of this discourse. He suggested three main stages of development. The first development stage, 1985-1995, focused on innovation as an interactive process within a system of innovation; the second stage, 2000-2010, concentrated on knowledge production and the features of a learning economy; and the third development stage (up to 2016) focused on the learning economy and "economics of hope" (Lundvall, 2016a, p. 4). The economics of hope refers to overcoming broader social concerns (such as inequality and wellbeing) and environmental concerns through the use of knowledge and innovation (Lundvall, 2016b).

This proposition is recognised in contemporary developing economy innovation and economic development literature, which critiques or recommends how knowledge and learning can catalyse innovation and economic development, for example, to overcome grand challenges (Kuhlmann & Rip, 2014, 2016, 2018). Work on this topic that emanates from developing economies covers themes such as the recognition of local R&D capabilities (Asim & Sorooshian, 2019), smallholder farmers (Tsan et al., 2019) and indigenous knowledge (Hooli & Jauhiainen, 2018).

5.2.2 Knowledge and learning in technological innovation system functions

In the TIS framework, the role of knowledge and its use are captured under two functions: Function 2: Knowledge development, and Function 3: Knowledge diffusion through information exchange in networks (Bergek et al., 2008; Hekkert & Negro, 2009). While the TIS framework recognises knowledge production and diffusion within actor networks, it does so in a limited way. For example, it calculates the number of R&D projects, patents and investments associated with an innovation, or how many workshops or conferences were held on a topic (Bergek et al., 2008; Hekkert & Negro, 2009). It, therefore, for the purposes of this study, does provide the level of focus required to understand actor agency or the effectiveness of the networks within which the actors operate.

Due to this limitation, the contextualisation and concepts of a knowledge network and the agents of leverage are explored further in Sections 5.3 and 6.1 respectively.

5.3 Knowledge networks, interactive and connected learning

As highlighted above, much innovation system discourse argues that knowledge production and diffusion hinges on the interaction of actors and individuals within a system to exchange knowledge (Adamides & Karacapilidis, 2006; Cooke et al., 1998; Cowan, 2004; Edquist, 2005a; Evers, 2014; Markard & Truffer, 2008; Metcalfe, 2007; Sammarra & Biggiero, 2008; Van Eijck & Romign, 2009). The social dimension of this interaction can be conceptualised as a process of social learning (Coenen et al., 2017; Grønning & Fosstenløkken, 2015). This occurs when knowledge is distributed socially between individuals (Gibbons et al., 1994) via a social network (Aral & Van Alstyne, 2011) thereby creating social capital.

The concept of "social capital" has numerous facets and definitions. For example, Putnam (1993, 2001) used it to explore the features of social organisation, such as networks, norms and trust, which enable mutually beneficial coordination and cooperation. Nahapiet and Ghoshal (1998, p. 243) defined it as "the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit". Burt (2005), Coleman (1988) and Culpepper (1996) explored other elements of social capital, such as how those within an organised network benefit and exploit the network to enhance productivity and solve problems or how they meet their obligations to and expectations of society. The concept is now adopted in business, political science and sociology discourse as a core framework for understanding the linkages between individuals in a society.

The concept of social capital is applied in knowledge network studies (see Chiang, 2007; Webb, 2008) and, to a lesser extent, in innovation studies (for example, Cantner & Stuetzer, 2013; Lock Lee & Guthrie, 2008; Thompson, 2018). Social capital in relation to systems of innovation research appears to be predominantly used by those studying regional innovation systems (RIS) (for example, Aragón Amonarriz et al., 2017, Chaminade & Vang, 2008; Njøs & Jakobsen, 2018; Putnam; 1993; Yoon et al, 2015). Njøs and Jakobsen (2018) suggested that one of the main reasons for the use of social capital in RIS is an often-perceived gap between how innovation systems and policy interact to stimulate and contribute towards the advancement of RIS. In addition, there is the importance of certain social attributes embedded in regions, which contribute to economic success (Njøs & Jakobsen, 2018).

It is argued that, without social capital, a knowledge network is ineffective (see Inkpen & Tsang, 2005; Thompson, 2018). These authors suggested that social capital stimulates, facilitates and provides the vehicle for the transfer of knowledge in the innovation process. Therefore, it is argued, an interactive and connected network provides an enabling environment for an effective and flexible innovation process (Moos et al., 2012; Yli-Renko et al., 2001). It also provides for the transfer of R&D into commercially viable products (Sammarra & Biggiero, 2008). In addition, it can add value to the study of social processes in networks (Inkpen & Tsang, 2005).

The act of networking is important for understanding the dynamics of knowledge-based societies. It links together different modes of knowledge production and use, and also connects different sectors, organisations or systems of society (Carayannis et al., 2016). Therefore, a knowledge network through which knowledge is produced and diffused is critical for the exchange of ideas and collaboration (Lundvall et al., 2009; Miguélez & Moreno, 2015; Pugh & Prusak, 2013; Scheel, 2002).

While multiple actors and actor networks have been recognised as playing an essential role in innovation development (Borrás & Edquist, 2014; Mossberg et al., 2018), there has been little conceptual or empirical consideration of their role in innovation and economic development policy (Bauer et al., 2017; Söderholm et al., 2019). This is even less so for the associated social or knowledge network. This is confirmed in Bauer et al.'s (2018) work on the dynamics of biorefinery innovation networks in Sweden. They noted that, while the interest in analysing networks in innovation and organisational discourse was increasing, few provided an empirical analysis of these dynamics.

Innovation development literature that has empirically analysed social dynamics tended to apply a social network analysis framework (understanding "who knows who" [Pathak et al., 2005, p. 1]) and used structural statistical models (for example, Bauer et al., 2018; Binz et al., 2014; Giuliani, 2005; Pyka & Scharnhorst, 2009). While these approaches allow for the analysis of actor connections and the spatial representation of network dynamics, they do not adequately explore knowledge dynamics and representation in a TIS.

While the phrase "knowledge network" is seldom explicitly used in innovation system literature, it is often alluded to in other terms. For example, in his exploration of a knowledge system framework for TIS for developing economies, Scheel (2002, p. 357) referred to the notion of "knowledge clusters". He suggested these clusters integrated different actors and provided an environment in which key actor competencies could be leveraged.

While not explicitly using the knowledge network concept, Chaminade and Plechero (2015) alluded to it in their work on the dimensions and mechanisms of international knowledge flows in Europe. They refer to "knowledge exchange" through formal and informal networks as mechanisms for knowledge acquisition and diffusion (ibid., p. 10). Identifiers of [knowledge] networks are provided in the literature, such as R&D contracts and alliances, research consortia, and communities of practice (Chaminade & Plechero, 2015; Wenger, 1998, 2013).

The concept has also been explored in quadruple helix literature. Carayannis et al. (2016, p. 1) referred to such networks as "knowledge systems", of which a key function is to generate and diffuse knowledge.

Perini (2009) and Metcalfe (2007) however, are the exception, clearly articulating the role of knowledge networks in the innovation process. Perini (2009) provides three interpretations of a knowledge network: (a) that it is a "metaphor" that represents the complexity of the innovation process (ibid., p. 60); (b) that it is the premise upon which to develop tools to analyse the interaction between actors; or (c) that it incorporates a wide range of activities founded on capabilities.

Metcalfe (2007) goes further by distinguishing those who generate and accumulate knowledge in a firm from those who make connections and ensure knowledge flows in the system. It is this explicit acknowledgement of individuals in a knowledge network that is of relevance to this study. This is explored further in Chapters 6 and 9.

5.3.1 Analytical dimensions of a knowledge network

To analyse the dimensions of the forestry-products biorefinery innovation system, I drew on two sources of work to inform this study. The first was Nahapiet and Ghoshal's (1998) analytical framework to explore the dimensions of social capital[33] in the formation of intellectual capital. The second was the work of Bonfim et al. (2018), who adopted Nahapiet and Ghoshal's (1998) framework, but within the context of innovation and technology development.

[33] See Sections 7.2, Functionality of the South African forestry-products biorefinery innovation system, and 3.3.2, Understanding knowledge and social capital, as well as Chapter 3 for descriptions of the different dimensions assessed in the knowledge network analytical Chapter 8.

The value of Nahapiet and Ghoshal's (1998) framework was that the dimension components provided a tool for assessing knowledge network ties, shared languages, narratives and relational issues such as trust (Thompson, 2018). These dimensions provided an explanation for what Culpepper (1996, p. 7) refers to as the "software of co-operative capacity", as opposed to the "hardware", which he refers to as the formal organisational structure. The fluidity and the informality of the network was defined structurally, relationally and cognitively to assess how it was connected, and who was connected to whom in relation to the interpretation of knowledge flows. It also provided a lens to identify those sitting outside of or missing in a knowledge network, referred to by Li et al. (2018, p. 4) as "black holes".

5.3.2 Barriers to knowledge network collaboration

It would be remiss to suggest that knowledge networks are homogenous and stable entities of activity. To the contrary, it has been contended that, due to their complexity, individuals and organisations may operate in a network that does not benefit their firm or sector's ambitions, and *vice versa* (Dosi et al., 2000; Gulati et al., 2006; Malerba, 2005; Perini, 2009). Actors within the network are also able to embed, control and to an extent manipulate innovation capacity. They can also influence the knowledge produced and diffused, and the types of projects undertaken (Coenen et al., 2017; Cowan, 2004; Gosselin et al., 2018; Metcalfe, 2007; Perini, 2009; Van Eijck & Romign, 2009). This suggests that knowledge is often unevenly distributed within a network and that power dynamics come into play (Boekema, 2000; Perini, 2009; Sorlin & Vessuri, 2007). Elements of trust, cohesion and cooperation therefore become imperative for building the foundations and continuation of a good innovation knowledge network (Grønning & Fosstenløkken, 2015; Morris & Barnes, 2006; Sułkowski, 2017; Todo et al., 2016). This is because decisions and actions are dependent on the cooperation of others in the network (Luna & Velasco, 2010; Thompson, 2018).

Trust is a fundamental component of social capital. It defines the ease with which people collaborate (Paldam & Svendsen, 2000; Thompson, 2018) and, therefore, the performance of an innovation project or process (Lee, 2016). Morris and Barnes (2006) suggested, in their study on the learning network in KwaZulu-Natal's automotive industry, that the issue of trust is exacerbated in developing economies. This exacerbation, they argued, was due to historic disadvantage, the establishment of a blame culture, state failures and weak innovation systems.

When issues of knowledge ownership or protection arise, for example with IP, trust and openness to sharing knowledge can be prohibited. Given that IP and the issuing of patents are indicators of knowledge generation in TIS, holding onto such knowledge would be deemed problematic, especially when it is withheld when known to be of interest to others.

Lock-in is another aspect that can hinder the effective transfer of knowledge in an innovation system. In the case of learning, "lock-in" refers to the retention of in-house technology and knowledge (Klitkou et al., 2015, p. 23). This retention inhibits the diffusion of knowledge and it can hinder a significant shift in the innovation process or in the transition towards more sustainable innovation (Foxon, 2002; Klitkou et al., 2015). It is argued that this type of lock-in is a manifestation of modern industrial economies: Dominant technologies and pathways are cemented in to ensure new knowledge or newcomers are suppressed (Kemp-Benedict, 2014; Klitkou et al., 2015; Oestreicher, 2012). Lock-in can also refer to the holding onto or protection of knowledge within a firm or by an individual, which can hinder the development of both (Oestreicher, 2012). Mariussen and Virkkala (2013) suggested that individuals are often unaware of the existence of lock-in. This is because it may be unintended or reinforced through "positive feedback mechanisms generated through successful cumulative learning experiences and innovation" (ibid., p. 158). Another prohibiting dimension of lock-in is knowledge protection or gatekeeping (Kesidou & Snijders, 2012), where those who are not in the firm or knowledge network cannot gain access to the knowledge or learning held within it. This leads to the notion of an open innovation system (see Chesbrough, 2006; Enkel et al., 2009; Marais, 2010, for further discussion on this concept). It also refers to the democratic access to and circulation of knowledge to expedite the innovation process. Here I particularly refer to the elements of the quadruple helix framework, which sets out a framework for enhanced collaboration and knowledge sharing (see Section 4.2.2).

Other inhibitors of knowledge exchange in an innovation system relate to agency, absorptive capacity and capability, and adopted behaviours within a network, all of which speak to the level of the individual in the knowledge network. These are explored further in Chapter 6.

5.4 Conclusion

In this chapter, actor knowledge and learning were acknowledged as critical components of innovation system discourse. The discussion on knowledge production has progressed since the 1990s through the work of a cohort of University of Aalborg academics – notably Lundvall, Johnson and Lorenz. By the 2000s, collective knowledge and learning became prevalent in various systems of innovation approaches. Examples were Malerba's (2005) research on sectoral innovation systems, and Asheim and Coenen (2005) and Fischer and Fröhlich's (2001) exploration of learning in regional systems of innovation.

It was also during the 2000s that distinctions between different knowledge production paradigms were articulated, notably codified and tacit knowledge, with specific reference to the latter and the importance of learning through doing in the innovation process. The need for this distinction between different knowledge production paradigms was justified, when Johnson et al. (2002) introduced the concepts of know-why, know-what, know-how and know-who. This was followed by further articulation in the late 2000s with the introduction of the concepts of the STI and DUI modes of innovation. It was suggested that these modes can function in parallel but the dominance of one form over the other should be avoided.

Most recently, knowledge and learning discourse has centred around its context within developing economies, and the recognition of social contexts. This correlates with the contextual setting of this study. This recognition is explored further in the Chapter 8, the analytical chapter that examines the dynamics of the South African forestry-products biorefinery innovation system's knowledge network.

Much of the knowledge network framing has been conceptual. There has been little empirical investigation of the dynamics of knowledge networks associated within innovation systems, especially in terms of the nature of the interactions between actors and individuals, and how knowledge is transferred within the system, as opposed to within or between firms. As such, this chapter explored knowledge network dynamics through the lens of social capital and knowledge network analysis. This approach recognises that knowledge is socially distributed between individuals in a social network. While knowledge network analysis is seldom used explicitly in innovation system research, it is an acknowledged concept used for assessing knowledge transfer within a predominantly organisational and firm context.

By drawing on the work of Nahapiet and Ghoshal (1998) and Bonfim et al. (2018) to develop a framework for assessing a knowledge network, this study contributes to a relatively under-researched area in TIS literature.

It would have been remiss of this chapter not to explore the barriers associated with the conceptualisation and application of knowledge network collaboration. Therefore, the most likely constraints of knowledge transfer within a TIS were highlighted. These constraints are lack of trust (central to social capital discourse), lack of openness and knowledge lock-in (technology and knowledge retention). As will become evident in the analytical Chapters 8 and 9, these inhibitive dimensions are crucial to the success or failure of individual agency within the network. The conceptualisation of the individual and their agency, capacity and capability within a knowledge network and the innovation process is investigated further in the following chapter.

Chapter 6:
Leverage professionals as innovation agency

The role of different actors through their interaction in the generation of knowledge and the learning process is important in systems of innovation discourse. These actors enable and embed innovation within a system. It is through the lens of the actor that agency in the innovation process is frequently cited. While Lundvall (2007a, p. 23) recognised that knowledge is “embodied in people and embedded in organisations”, the level of the individual is seldom (aside from some examples in RIS research) presented as agency. As such, the understanding of individuals and their capacity within an innovation system is limited (Hansen & Coenen, 2017). It also does not assist with identifying how they enable innovation through knowledge generation and diffusion (Mossberg et al., 2018).

Criticism has been levelled at both system of innovation literature in general, and TIS literature. The former is criticised for its tendency to “privilege the structure while downplaying actors’ agency” (Mossberg et al., 2018, p. 86) and TIS is criticised for its requirement to elaborate on political agency and the role of actors in shaping the development of the TIS (Flanagan et al., 2011; Hansen & Coenen, 2017; Watkins et al., 2014).

Given this criticism, I believe there is a need to reach a better understanding of the role of individuals within a TIS and its associated knowledge network. This is due to my suggestion that connected individual agency is central to increasing the uptake of biorefinery innovations in the South African forestry-products sector, a sentiment supported by Mossberg et al. (2018). They stated that “without sufficient understanding of actors, their roles and agency, it is difficult, not to say impossible, to adequately analyse and understand the dynamic interactions and relations between actors and their importance for the sustainability transitions” (ibid., p. 2). This would also apply to the biorefinery process, as it has been argued that, while the strategy for implementation is promising, application is challenging. Most reasons given for the challenges are directly or indirectly associated with an individual, notably lack of competency and failure to establish strategic partnerships along a value chain (Hansen & Coenen, 2017).

Given this intention to reach a better understanding of the role of individuals within the forestry-products biorefinery innovation system, the first section of this chapter proposes the concept of the “leverage professional”. This is an abstract concept I developed and applied in this study. The concept has two distinguishing elements: first, that of agency (leverage), and secondly, that of being a professional. The latter refers to individuals who are recognised for their proficiency and expertise within a network.

The second section of the chapter draws predominantly on organisational management perspectives to develop a framework to understand the characteristics required of individuals to leverage their agency and, by doing so, to overcome barriers to operation within an effective TIS. This is based on the premise suggested by Nieminen (2004, p. 60) that, "even though innovativeness is understood as a social phenomenon, personal qualities, knowledge, skills and motivation also have an important role to play."

6.1 The leverage professional concept

The notions of leveraging change and of agency are core components of the leverage professional concept. While difficult to provide a concise definition of *agency* (O'Donovan, 2017), in principle it refers to the motivation, aspiration and determination of an individual to act and make change happen. This can be on their own or as part of a collective (Caldwell, 2003; Cloete, 2017; Dale, n.d.; Van Poeck et al., 2017). In addition, I adopted Ahearn's (2001, p. 112) conceptualisation of agency as "the socio-culturally mediated capacity to act".

In contemporary sustainability research, a focus on the role of "change agents" is becoming commonplace as the importance of these individuals as activists, initiators, facilitators or intermediaries is realised (Grandia, 2015; Kraft, 2017; Van der Heijden et al., 2012; Van Poeck et al., 2017). Avelino et al. (2017, p. 3) suggested game changers operate within a "contextual dynamic that is perceived by social actors as changing the dominant logics, rules, and conditions of engagement of existing socio-technical regimes at multiple scales (global, national, local)". Therefore, they do not operate in the abstract, and their intentions and actions are within an applied space. For this reason, it can be proposed that change agents are comfortable challenging established world views and social norms. They also inspire followers and early adopters, as they provide constant and enthusiastic motivations for change (Caldwell, 2003; Grandia, 2015; Kraft, 2017; Van Poeck et al., 2017).

Drawing on Lunenburg (2010) and Swilling (2016), change agents are able to operate within the mainstream dynamics of a TIS or be more marginal. For example, they can be situated in a firm or government department as an employee (mainstream) or seated outside a network or firm yet have agency (marginal, such as a consultant).

While a change agent may be deemed an individual who has the aspiration, motivation and drive to make change happen, leverage refers to actual intervention or the point (the individual) at which significant change happens (Abson et al., 2017; Meadows, 1999; Riechers et al., 2019). Literature on the conceptualisation of leverage are largely located within management, social science, global health and sustainability discourse (Lee, 2015). It tends to focus on the physical location of intervention within a system (Meadows, 1999; Senge, 1994), as opposed to focusing on the individual as the lever.

This should not detract from the value of the concept of leverage (whether location or individual). As the emphasis is placed on the purpose to leverage, which is to move the system (Ritchie-Dunham, 1998), it is on this premise that a change agent would be considered an individual who motivates, facilitates and aspires to significantly advance an innovation or system.

Use of the term professional in this study is deliberate because it provides a focus on specific individuals in the South African forestry-products biorefinery innovation system, their agency and roles within it. However, the concept of a professional[34] is much debated (Carr, 2014; Evetts, 2014; Sciulli, 2005). It was first introduced in research in the 1950s and 1960s, and focused on occupations and institutions (Evetts, 2014). For example, the work of Hughes (1958) linked professionals with occupations, and explored the notion of professional identity. He asserted that professional identity is associated with shared experiences, common understandings and expertise, the latter alluding to educational background. Through this mutual recognition, professional morality, values and codes of conduct are created, regulating how to operate and perform as an individual or collaboratively (Evetts, 2014; Freidson, 2001; Van Poeck et al., 2017).

While it is argued that classifying professionals by occupation is questionable (Carr, 2014), it can be assumed that most leverage professionals in a biorefinery innovation system will hold design, engineering, technical and managerial roles. They are also seen as generators of innovation within organisations, and originators of R&D (Kraak, 2007; OECD, 2007). While these occupational categories are fitting, the idea of innovation lying in the hands of engineers, for example, is problematic. It suggests hierarchy, bureaucracy and managerial control (Evetts, 2009). For those who do not carry these titles, this can create a sense of not being worthy.

[34] For a detailed assessment and discussion of professionalism as a construct, see Evetts (2009).

However, they may be just as effective change agents in an innovation system. I argue that other competencies and roles are required, such as leadership, communication, negotiation, collaboration and coordination (Bouraoui et al., 2011; Cooke et al., 1998; Lindberg & Teras, 2014; Luna & Velasco, 2010; Markides, 2005; Morris & Barnes, 2006). Therefore, given the necessity for these competencies, I suggest that the use of a strict occupationally directed characterisation of a professional would not be appropriate. A more fitting definition is that provided by the Australian Council of Professions (2019, para. 1), which defines a professional as:

> "[Being] accepted by the public as possessing special knowledge and skills in a widely recognised body of learning derived from research, education and training at a high level, and who are prepared to apply this knowledge and exercise these skills in the interest of others … [and] … are governed by codes of ethics, and profess commitment to competence, integrity and morality, altruism, and the promotion of the public good within their expert domain. Professionals are accountable to those they serve and to society."

This aligns with the notion of a leverage professional as a sociological determinant, with a non-hierarchical, peer-determined and recognised status of expertise in a knowledge network. This as opposed to an organisationally-determined construct (Jemielniak, 2010; Larson & Starr, 1993).

Therefore, for the purposes of this study, I propose the concept of a leverage professional as follows:

> They are an individual recognised for their expertise, knowledge, competencies and integrity, from which they individually or collectively significantly catalyse a shift in an innovation system.

6.2 Leverage professionals situated within an innovation system

This section explores the theoretical dimensions of leverage professionals as role players. It references behavioural preferences, knowledge and the competencies required for an effective TIS and innovation process. As alluded to earlier, leverage professionals may act autonomously or work collaboratively to catalyse change and seek solutions to problems (Culpepper, 2004; Mazzucato, 2014). I suggest that this exploration includes the contribution they make and the mechanisms by which they conduct their leveraging activities within a TIS and its associated knowledge network. This premise is drawn from green skills research undertaken on occupations in certain sectors in South Africa (see Jenkin et al., 2016; Rosenberg et al., 2017; Ward et al., 2016). This research identified that individuals sit within a wider network of employees on whom they rely to assist in the delivery of work, or to inform decision-making (Jenkin et al., 2016).

In addition, depending on how they operate, they can also significantly determine the knowledge flows in a sector (Perini, 2009). This suggests the leverage professional plays two roles within a TIS. The first role is as an individual with unique traits (such as passion, drive, abilities, values and leadership qualities). The second role is as an employee of an organisation or member of a social or innovation network. For the latter, their identity is organisational or group oriented, which means they present this identity externally in alignment with brand image, corporate reputation, and adherence to defined corporate language (Balmer, 2008; Tourky et al., 2018). Therefore, the behaviour an individual portrays in this regard is based on their perceived status or position, social or organisational (Sherstyuk et al., 2016).

While innovation and economic development literature, to a lesser extent, explores social capital in innovation systems (for example, Chaminade & Roberts, 2002; Chaminade & Vang, 2008, Njøs & Jakobsen 2018; Thompson, 2018; Yoon et al., 2015), research is lacking on understanding the roles individuals play within a TIS, how they are connected and support each other (social capital) and whether their traits and challenges determine or influence their behaviour and abilities. The most aligned frameworks are situated in organisational literature, notably those that consider individuals within teams, team dynamics and determinants of high-performing teams. Drawing on this body of work, yet with the TIS as reference, the concept of a team in organisational literature was interpreted for this study as a group of leverage professionals. These being individuals "with mutual accountability that work interdependently to solve problems or carry out work" (Kirkman & Shapiro, 2001, p. 700).

As alluded to earlier, the leverage professional as change agent in a network can play a diversity of roles, for example, as expert, facilitator or coordinator, activist and catalyst. These roles can be played out concurrently (Hesselbarth & Schaltegger, 2014), and are dependent on what is required of a situation and determined role (Belbin, 2013; Sherstyuk et al., 2016).

To understand the role of individuals within a TIS, various frameworks and concepts from organisational literature were assessed. Frameworks included Myers Briggs' type indicator profiles and Belbin's team role classification (Belbin, 2010, 2019). Concepts investigated included boundary spanners and brokers, tempered radicals and positive deviants. These are discussed further below to ascertain their relevance for developing an analytical framework for assessing leverage professional traits and roles in South Africa's forestry-products biorefinery innovation system.

6.2.1 Composition of leverage professionals within an effective network

Within organisational literature and praxis, two models for determining the composition of team roles in relation to collaboration and performance have been widely applied, notably Myers Briggs' type indicator profiles and Belbin's (2010, 2019) team role taxonomy. Both approaches originated in the early 1990s when interest emerged on how to develop high-performing teams to maintain competitive advantage (Higgs, 1996; Swailes & McIntyre-Batty, 2002). While both proposed useful frameworks for assessing characteristics and individual's behavioural team preferences, it is Belbin's taxonomy that has attracted the most theoretical and empirical attention (for example, Aritzeta et al., 2007; Flores-Parra et al., 2018; Gibson & Nesbit, 2006; Higgs, 1996; Mostert, 2015; Sherstyuk et al., 2016). In addition, of all the approaches identified, Belbin's (2010, 2019) team role classification provided the most useful classification. It identifies nine individual behavioural preferences or roles within a team. He also applied the taxonomy to a variety of organisations, such as government, and not just the firm (Belbin, 2013).

Belbin's emphasis is that, for a team [aka an innovation network] to perform well, be effective and well balanced, it requires a combination of different roles (Belbin, 2019; Genc, 2017; Sherstyuk et al., 2016). In comparison to other approaches, Belbin provided a more diverse range of behavioural classifications, as well as a structure for the self-profiling individuals in a team (Flores-Parra et al., 2018). Belbin's categories are based on initial research undertaken in the 1940s and 1950s, which distinguished between "task roles and socio-emotional roles" (Sherstyuk et al., 2016, p. 97). The former focused on problem-solving, and the latter on the emotional connectedness of a group (Benne & Sheats, 1948). In 1981, on the basis of a nine-year study, Belbin developed a framework on team building and effectiveness (Sherstyuk et al., 2016). The aim of the framework was to quantify individuals' team role preferences (Genc, 2017). This first taxonomy contained eight roles (Belbin, 2013). A team role was defined as a "pattern of behaviour characteristic of the way in which one team member interacts with another in order to facilitate the progress of the team as a whole" (Sherstyuk et al., 2016, p. 99). By 1993, some of the original roles were adjusted and a ninth role was added to form the basis of the taxonomy (Sherstyuk et al., 2016) that is still applied today. Belbin's nine team role types are (Belbin, 2019; Flores-Parra et al., 2018):

1. *Coordinator* – coordinates and controls the activities of a team
2. *Resource-investigator* – develops ideas and is a good external networker and extrovert
3. *Team worker* – communicates well with others and is people-oriented
4. *Plant* – is creative, imaginative and an idea generator
5. *Monitor-evaluator* – is prudent and analytical
6. *Implementer* – is task-focused and practical
7. *Completer-finisher* – is detail-focused and finishes tasks
8. *Shaper* – is challenging and dynamic
9. *Specialist* – has high technical skills and in-depth knowledge

See Appendix D for descriptions of each role, and Chapter 9 for their application in this study.

Belbin's team role framework, even though recognised as pragmatic with theoretical grounding, has been criticised, most notably in respect of its lack of theoretical psychometric framing (Furnham et al., 1993; Prichard & Stanton, 1999) and whether all nine roles are required for a network to function effectively. It has also been criticised for assuming that understanding within a network is mutual and that knowledge is evenly distributed (Genc, 2017; Klein et al., 2004). The latter assumes individuals in a team are strategic with regard to their preferred behaviours. In addition, it is assumed that the dynamics of the team within which they operate remain static (Intrepid., 2009). Belbin has acknowledged the critique levelled at the framework (Intrepid., 2009) and, while continuing to update the associated discourse, noted the "staying power" (Belbin, 2013, preface) of the taxonomy as recognition of continued theoretical and empirical interest.

6.2.2 Other individual role player classifications

While Belbin covers the extent of a variety of individual roles within a team or network, other individual role classifications were identified. These are worthy of exploration, such as, boundary spanners (Aldrich & Herker, 1977; Safford et al., 2017; Tushman & Scanlan, 1981), brokers (Burt, 2005), intermediaries (Hermann et al., 2016; Kanda et al., 2018), system builders

(Musiolik et al., 2016), tempered radicals and positive deviants (Meyerson, 2001, 2004; Pascale et al., 2011).

Brokers and boundary spanners

The role of the "broker" is one of the more commonly referred to roles in innovation network research. This is because brokers are considered as intermediaries between individuals and groups and facilitate knowledge diffusion between the two. This function can drive the innovation process (Chen et al., 2015; Giuliani & Bell, 2005). A broker is the antithesis of a gatekeeper who can negatively manipulate the flow of knowledge (Chen et al., 2015; Graf & Krüger, 2011).

In his work on social capital, Burt (2005) referred to brokers as individuals who have the ability to bridge the gap between individuals or groups of individuals. They are characterised as being creative, implementors and coordinators – a combination of traits associated with Belbin's resource-investigator, team worker and plant roles.

The broker concept aligns strongly with that of a "boundary spanner". The term has been used since the 1970s and 1980s by authors such as Adams (1976), Aldrich and Herker (1977) and Tushman and Scanlan (1981), as well as within Wenger's (1998, p. 185) concept of "communities of practice". While multiple definitions exist, boundary spanners tend to be described as individuals who straddle two or more groups or individuals, for example, between producers and users (external) or within an organisation between departments (internal) (Safford et al., 2017). They are said to enable communication, too often be accountable to both groups and to buffer, filter, protect, represent, interpret and negotiate between individuals and groups. This may also include activities such as coordination or undertaking research to support and share between groups or individuals, with the intention of finding areas of beneficial overlap (Alexander et al., 2016; Ansett, 2005; Ernst & Chrobot-Mason, 2011; Safford et al., 2017).

Hsu et al. (2007, p. 1133) and Witt and Zellner (2007) suggested that not only do boundary spanners play the multiple roles listed above, they are also effective at understanding the "coding schemes" and contexts of both sides of the boundary. This enables them to interpret, pre-empt or respond to the dynamic nature of interaction and change. Thus, boundary spanners can control and influence the type, flow and coordination of knowledge produced and diffused through the unification of a network.

With regard to function, boundary spanners express character traits such as being competent, skilled, high performing and trustworthy. They also hold some form of status within and between groups, and are seen as good communicators and leaders who can handle diversity (Agnihotri et al., 2014; Bercovitz & Feldman, 2007; Cohen & Levinthal, 1990; Ernst & Chrobot-Mason, 2011; Hsu et al., 2007; Lundberg, 2013; Safford et al., 2017).

Both brokers and boundary spanners present a combination of traits associated with Belbin's coordinator, resource-investigator, team worker and plant roles.

Tempered radicals and positive deviants

In addition to the concepts of boundary spanners and brokers, tempered radicals (Ansett, 2005; Meyerson, 2001) and positive deviants (Green, 2016; Pascale & Sternin, 2005; Seidman & McCauley, 2008) are also worthwhile exploring, particularly from the perspective of innovation arising from creative disruption (Christensen et al., 2015).

"Positive deviants" may be boundary spanners. However, they are less likely to conform to the system, facilitate or mediate and they are recognised for departing from the established path or conventions. While working within the same confines or having access to the same resources as others, they consistently discover innovative ways to function (Pascale & Sternin, 2005; Seidman & McCauley, 2008). They may be discordant, creative or disruptive, may purposefully create tension to catalyse an intended positive outcome and innovation, and are likely to resist the norm (Gulbrandsen, 2004). In many instances, particularly in high-tech businesses such as Google and Uber, they are identified for their high level of work intensity, output, creativity and ability to challenge. They are therefore given licence to operate imaginatively (Hill, 2012; Seidman & McCauley, 2008). If not operating within a conducive environment, they can struggle to function within the confined norms of traditional organisational structures. Working in an organisation as a change agent is often an uncomfortable fit. Change agents are often in a constant state of trying to align with the core visions and culture of the firm, yet also trying to change the system from within (Meyerson, 2004; Quinn & Meyerson, 2008). A similar term to that of the positive deviant proposed by Meyerson (Meyerson, 2001, 2004; Quinn & Meyerson, 2008), is that of a "tempered radical", who portrays similar characteristics.

From the perspective of leverage professionals, positive deviants and tempered radicals may be considered disruptive because they do not always abide by the subtle codes and nuances of an established network. It could therefore by argued that they are much needed to transition South

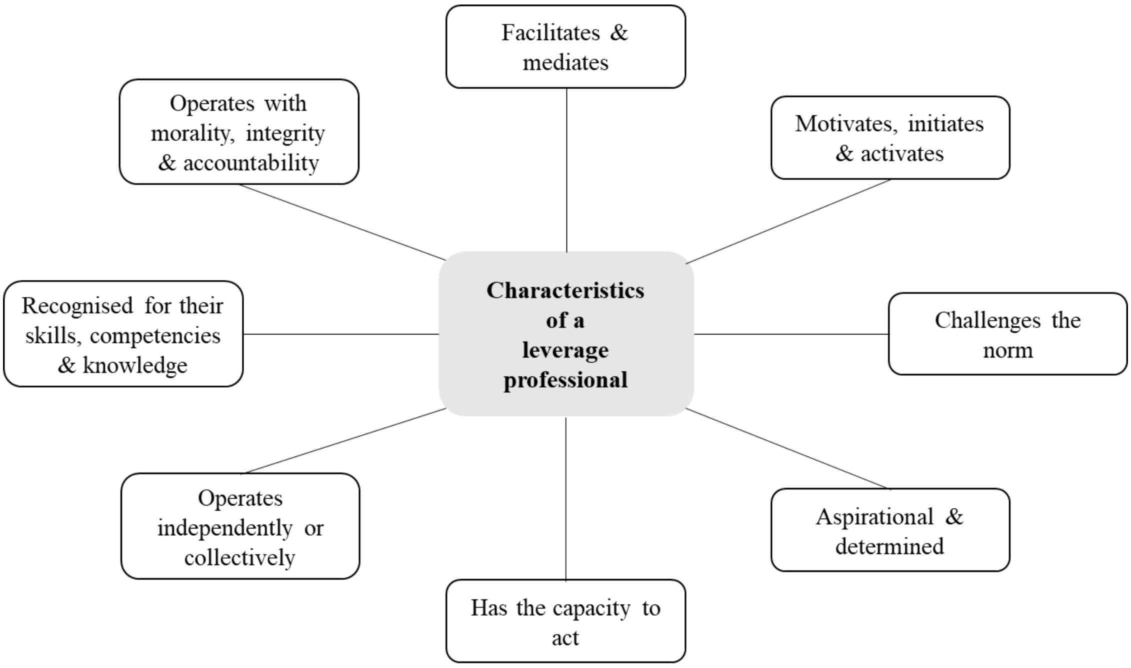
Africa's forestry-products sector, which has historically entrenched norms and systems. They may be able to introduce and escalate a potentially radical solution, such as biorefinery technologies, which are likely to require some form of disruption.

6.3 Conclusion

This chapter argues for the value of recognising and conceptually understanding the role of leverage professionals as a social dimension of a TIS. It does so firstly, by introducing the concept of a leverage professional; and secondly, by providing a set of role player classifications required for an effective TIS.

The concept of a leverage professional has been informed by research on change agency in sustainability discourse. It has also been informed by the notion of a professional as someone who has experience, competencies and knowledge, yet adopts a level of morality, integrity and accountability. Drawing on these theoretical insights, Figure 4 highlights the proposed core characteristics associated with a leverage professional. Based on the review of organisation literature, Figure 5 illustrates the hybrid leverage professional roles required for an ideal TIS.

Figure 4: Proposed characteristics of a leverage professional[35]



[35] Developed by the author.

Figure 5: Hybrid leverage professional role taxonomy[36]

Co-ordinator
(Boundary spanner / broker)

- Co-ordinates & manages
- Leadership & control
- Delegates
- Confident in abilities
- Integrative approach

Resource investigator
(Boundary spanner / broker)

- Ideas & opportunities seeker
- Enthusiastic & optimistic
- Networker
- Facilitates & shares knowledge & information
- Advocate

Teamworker
(Boundary spanner / broker)

- Co-operative, perceptive & diplomatic
- Filters, transacts, mediates & protects
- Good communicator & listener
- Facilitates common purpose
- Person-oriented & integrative

Plant
(Boundary spanner / broker / tempered radical / positive deviant)

- Creative & imaginative
- Visionary
- (Unconventional) problem solver
- See things others do not
- Depart from the norm
- Passionate & committed

Monitor-evaluator
(Boundary spanner / positive deviant)

- Strategic & discerning
- Perceptive with good judgement
- Conservative
- Identifies efficiencies & overlap
- Sense of morality and purpose

Implementer
(Boundary spanner)

- Planner & strategist
- Practical, reliable & efficient
- Action-driven / task-oriented
- Producer of tools to enable communication

Completer-finisher

- Conscientious
- Pedantic & perfectionist
- Finishes tasks / projects

Shaper
(Tempered radical / positive deviant)

- Dynamic, driven & courageous to overcome obstacles
- Catalyst & motivator
- Activist
- Persistent & committed
- Challenges world views

Specialist
(Boundary spanner / broker)

- In-depth knowledge & technical skill
- Credible expert
- Dedicated & focused
- Access to diversity of information
- Facilitates knowledge flow
- Self-starting

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[36] Derived from and informed by: Ansett, 2005; Appelbaum et al., 2007; Belbin, 2010, 2013, 2019; Burt, 2005; Chen et al., 2015; Ernst & Chrobot-Mason, 2011; Hsu et al., 2007; Lundberg, 2013; Meyerson, 2001; Quinn & Meyerson, 2008; Seidman & McCauley, 2008; Sparks, 2005.

As little work was identified on the role of leverage professionals (or similar) within TIS, and almost none in biorefinery literature, organisational literature proved useful. It identified and set out a model for analysing role players within teams and groups of individuals working together. Especially relevant was the work, mainly by Belbin but also by other authors, on the concepts of broker, boundary spanner, tempered radicals and positive deviants.

As indicated previously, the role of disruptor fits well with the leverage professional definition. It is disruptors (aka Belbin's shapers, or tempered radicals and deviants) who are most likely to disrupt current business-as-usual forestry-sector practice and catalyse the transition towards biorefinery acceptance and application. This proposition aligns well with Schumpeter's notion of creative destruction. Schumpeter suggested that "economic innovation is fueled by entrepreneurs who discover better ways of doing things (creative component), and their success leads to the collapse of old companies and methods (destructive component)" (McGrath, 2014, para. 1).

This chapter addressed a suggested theoretical gap[37] in TIS literature by providing a classification framework to examine the characteristics and roles of leverage professionals within a TIS, with a particular focus on knowledge generation and diffusion. As such, this study brings an enhanced dimension of analysis to TIS discourse.

In addition, the theoretical framing gave me the endorsement to incorporate the level of the individual within the knowledge network. These individuals are recognised as generators and diffusors of knowledge, and therefore as one of the necessary dimensions of a TIS. The application of this analytical tool is presented in Chapter 9.

[37] Except for some explicit examples in RIS, see Cooke (2013).

Chapter 7: South Africa's forestry-products biorefinery innovation system's structure and functions

This chapter is the first of three analytical chapters that are grounded in the previous theoretical Chapters 4, 5 and 6. Chapter 3 provided the theoretical foundation for the selection and development of the research method and questions. It also conceptualised the underlying theory and provided the contextual setting of South Africa's forestry-products sector. In this way, these earlier chapters provided the theoretical framework, anchor, and vision for the empirical analysis presented in the following chapters, and the knowledge of how to apply and interpret the theory.

Before launching into this first analytical chapter, I provide a brief reminder of what was covered in the previous chapters. I also illustrate how I adapted and used TIS, knowledge and knowledge network, and individual's in team behavioural concepts and frameworks to devise some of my own classifications and framework for analysis.

Building on Chapter 2 (which provided a contextual understanding of South Africa's forestry-products sector), this chapter provides an analysis of the country's forestry-products biorefinery innovation system. It uses the TIS framework to assess the structural characteristics, and four of the six functions proposed by Bergek et al. (2008); Markard (2018) and Walz et al. (2016). These four functions are the influence of the direction of the research, entrepreneurial activities and experimentation, market formation, and legitimisation of biorefinery technologies.

The knowledge generation and diffusion through networks, and human resource mobilisation (aka leverage professionals) functions are covered extensively in Chapters 8 and 9, respectively.

The structural components and characteristics of the sector provide a systematic assessment of the biorefinery network. This is an exercise that tends to be lacking in academic work (Bauer et al., 2018).

Chapter 4 provided the theoretical framing to the TIS and quadruple helix approaches. While the TIS framework provides a systematic approach for understanding the structure and functions of South Africa's forestry-products biorefinery innovation system, it does not, in the main, explicitly allow for the analysis of the role of civil society in the innovation process. The quadruple helix model, on the other hand, recognises the complexity of an innovation systems' context and argues for the inclusion of civil society as an equitable actor in the innovation process. As such, this chapter will address the first research question: How collaborative is South Africa's forestry-products biorefinery innovation system?

From the perspective of collaboration, the analysis of the biorefinery TIS will refer to proposed criteria for assessing an ideal system of innovation (see Chapter 4). This includes an assessment of the actors, network ownership and governance, trust, translation, language and communication, negotiation, demonstration, mutual benefaction, inclusivity, efficacy and efficiency.

This chapter therefore contributes to TIS literature in three ways: first, it provides empirical insight on a developing country's TIS; second, it undertakes a systematic assessment of the characteristics of a biorefinery network; and finally, it incorporates a set of ideal collaboration characteristics as assessment criteria.

7.1 Structural characteristics of the biorefinery innovation network

In this section, I am interested in understanding the structural characteristics and dynamics that determine how actors in the South African forestry-products biorefinery network are connected. I also explore the reasons for their interaction, and the rules and norms determining the level of their activity. These set the foundation for understanding the TIS functions in the current system, and elements that may hinder or enhance collaboration. The innovation system is described using functions[38] outlined in the TIS framework, as opposed to a description of actors and groups in the system.

In the main, this chapter presents the findings from the analysis of interviews with leverage professionals in the South African forestry-products biorefinery network to provide empirical evidence and insights.

7.1.1 Actor connectedness and roles within the network

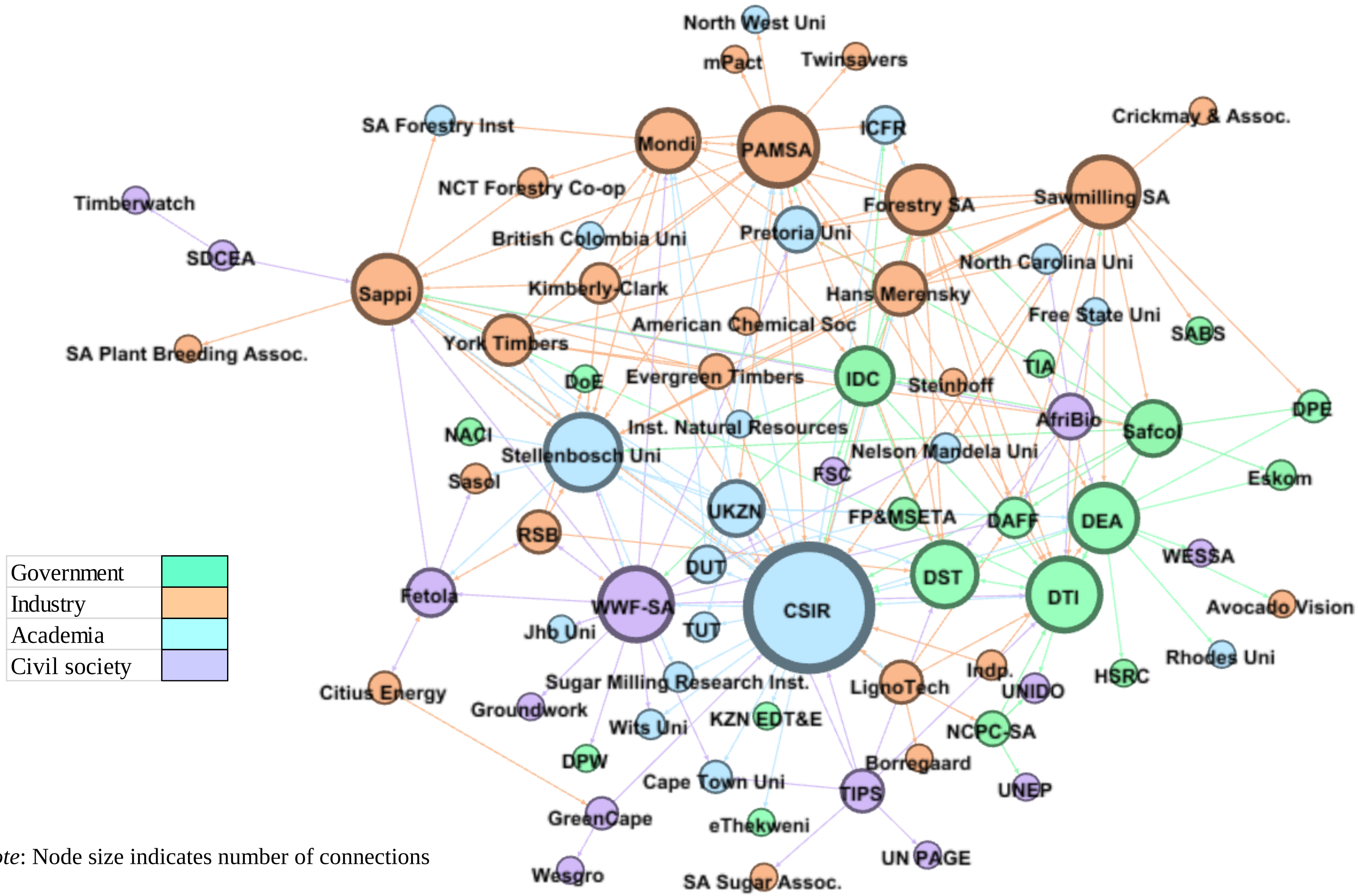
This section describes the nature of the connections between the actors (industry, government, academia and civil society) in the South African forestry-products biorefinery innovation

[38] The TIS functions are knowledge generation and diffusion, influence of direction of the research, entrepreneurial activities and experimentation, market formation, legitimisation and resource mobilisation.

system. It also explores the reasons why connections are established, thereby suggesting collaboration between actors.

Using the network analysis tool, Gephi, a sociogram (Moreno, 1934) of the innovation network is presented in Figure 6. The sociogram was developed using a series of nodal and edges data gathered from the interviews. The "node" represents an actor group cited by a leverage professional, and the "edges" represent the links between actor groups. The latter were identified by leverage professionals as individuals or entities they engaged with regularly in relation to biorefinery, innovation or similar topics. By running this data through Gephi, a social network (sociogram) was produced. It presents an indicative structure and the connections between actors in South Africa's forestry-products biorefinery innovation system. The size of the nodes represents the number of connections per actor, and therefore their centrality and position within the network (Grandjean, 2015).

Figure 6: South African forestry-products biorefinery innovation system actor network (August–October 2018)



Note: Node size indicates number of connections

The visualisation of the network suggests a cohesive and connected group of actors. However, this is misleading, as observed in the scaling of the actor nodes. As can be seen, certain actors are more central to the network, because they have the most connections. These central actors are the CSIR (a national research institution), Stellenbosch University (academia), PAMSA (trade association), the World Wide Fund for Nature South Africa (WWF-SA) (civil society), Sappi and Mondi (industry), the national departments of the DST, the Department of Trade and Industry (DTI) and the DEA (government); and Sawmilling SA and Forestry SA (trade associations). These core actors are all connected to some degree, through having dominant roles in either biorefinery- or forestry-products.

A secondary level of less-connected actors falls within the main frame of the network. These actors tend to be involved indirectly through forestry-focused research or are investing in biorefinery opportunities. Falling within this group of actors are the Universities of Pretoria and KwaZulu-Natal (academia), the Industrial Development Corporation of South Africa (IDC) and the Department of Agriculture, Forestry and Fisheries (DAFF) (government), as well as forestry and mill owners such as SAFCOL (a state-owned entity), York Timbers and Hans Merensky Holdings (industry).

The network reflects a typically triple-helix alliance, with industry, government and academia dominance. All major pulp and paper manufacturers and sawmillers are to some degree involved in R&D or biorefinery discourse. The trade associations also play an important role in lobbying government on behalf of their members. The DST is the key government department dealing with biorefinery innovation, and provides policy, strategy and financial support. The DEA on the other hand plays a more legislative role and has a vested interest in job creation and eradicating alien vegetation. The notable research institution funded by government is the CSIR. The institution contributes in two significant ways: first, by addressing biomass waste through their biorefinery industry development facility; and second, as coordinators of the DST's Waste Research, Development and Innovation (RDI) Roadmap. Universities are involved in two main ways. Their first involvement is through forestry-products and pulp and paper biorefinery-specific research and education. This is mainly undertaken in chemical engineering departments, notably at Stellenbosch University and the University of KwaZulu-Natal. The second main involvement is in forestry-science activities, research and education at the Universities of Pretoria, Stellenbosch and Nelson Mandela.

It is reasonable to assume that the dominance of this triple-helix structure is due to the South African government's innovation policy, strategy and support. It repeatedly emphasises industry, government and academia as key role players in the NIS (see Cele, 2018; Kraemer-Mbula & Sehlapelo, 2016; Parliamentary Monitoring Group, 2012; Scerri, 2009).

Geographically, most actors operate in Gauteng, KwaZulu-Natal, Mpumalanga and the Western Cape. This aligns with the location of tree plantations, sawmills, timber producers and pulp and paper plants in Mpumalanga and KwaZulu-Natal. Trade associations and national government departments are predominantly located in Johannesburg or Pretoria, Gauteng. Universities, research institutions and NGOs are located throughout the country, except if focused on a specific regional issue, like the South Durban Community Environmental Alliance (SDCEA), whose efforts are linked to industry in the South Durban basin.

A few international actors, predominantly with a funding role, are linked to the South African network, such as the United Nations Environment Programme (UNEP). In addition, Mondi and Sappi have global operations and value chains, and LignoTech's parent company Borregaard is situated outside South Africa.

While the actor map suggests several players participate in the TIS, the reality is that only a few players are actively involved. Those that are most active have particular areas of interest, notably:

- *Industry:* Sappi (pulp and paper biorefinery implementation and pilots), with LignoTech a smaller player (pulp and paper biorefinery)
- *Trade associations*: PAMSA (pulp and paper research intermediary)
- *National government departments*: DST (biorefinery and bioeconomy mandate) and the DoE (biofuels and renewable energy)
- *Academia and research institutions*: Universities of Stellenbosch and KwaZulu-Natal (the latter in conjunction with the CSIR); and the CSIR (Biorefinery Industry Development Facility and techno-economic research), and TIPS (biorefinery research to inform trade and industry policy)
- *Civil society:* WWF-SA (aviation biofuels research and advocacy)

It is highly likely that the actor network will continue to expand and will become more cohesive and mature as green and circular economy activity in the country increases. This includes an increased desire to add value to biomass and the byproducts generated in manufacturing processes, and government investment to do so (see Bek et al., 2017; Borel-Saladin & Turok, 2013; CSIR, 2018; Death, 2014; Kaggwa, 2013; Maia et al., 2011; Montmasson-Clair, 2012; Montmasson-Clair et al., 2018; Musango et al., 2014; SA Department of Economic Development, 2011; Sappi, 2017, 2018b; Tshangela et al., 2016; United Nations Environment Programme [UNEP], 2013). This expansion was witnessed during the latter half of this study when new intra-networks were set up. One example of expansion occurred at the Western Cape Alien Vegetation Biomass Expo Day (Western Cape Government, 2019). This event catalysed the establishment of a platform of stakeholders interested in valourising biomass. The second example was the drafting of a proposal by the DEA to garner funding for a South African bioeconomy network (G Barnes, personal communication, December 2, 2019). This expansion indicates the system's transitioning to the next level of maturity

7.1.2 Motivations for actor interaction

The desire to solve problems, undertake research, develop policy and strategy, and advocate for market creation were the main reasons given for collaboration. This reflects the importance of actor collaboration in innovation systems – a key component of system of innovation discourse (Bergek et al., 2010; Choi et al., 2013; Edquist, 2005b; Hekkert et al., 2007). The quotes below illustrate some of the reasons given by leverage professionals for collaboration.

> "[I]n South Africa we work with government as much as we can and often in collaboration – usually for policy development, and with WWF to test the [Roundtable on Sustainable Biomaterials] RSB standard." (A Baldo[39], Interview 9, October 15, 2018)

> "[W]e're having strategic and potentially impactful discussions, and at the same time working with the guys in alien vegetation that carry biochar out." (G Barnes[40], Interview 1, October 8 & 18, 2018)

> "My function and role is to run the facility and to make sure that it meets its objectives, which are to develop and implement biorefinery technologies in South Africa for the

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[39] Arianna Baldo is the RSB's lead for Africa and the Middle East, and strategic projects. The RSB is an international membership-based initiative that offers sustainability and bio-materials certification. Arianna is involved in the *Waste to Wing* project, a collaboration between RSB, Fetola Foundation, WWF-SA and SkyNRG. It is funded by the European Union's Switch Africa Green Programme.

[40] Garth Barnes is the Deputy Director of Advocacy and Risk Management in the national DEA. Garth's role includes business strategy development, advocacy, stakeholder engagement, and education for sustainable development. He is the lead for the Alien Vegetation Biochar Knowledge Network.

benefit of the forest products industry, but also to get buy-in from the industry." (Prof. Sithole[41], Interview 27, August 1, 2018)

"Our Steering Committee consists of technical people from each of the [PAMSA] members. We try to develop projects that are common to all and are pre-competitive." (M Nash[42], Interview 15, September 6, 2018)

An additional and notable feature of the network – identified in leverage professional interviews – is the solid, and long-standing industry-academic relationship (duo-helix). The role of trade associations in academic instruction and knowledge transfer is important within the South African forestry-products context. Most notably, PAMSA, in collaboration with the pulp and paper industry, develops training programmes, provides scholarships and sponsors academic posts (Rypstra, 2011).

PAMSA's role and potential power within the industry-academia collaboration is worth further commentary. All the academic respondents (I Kerr[43], Interview 30, August 7, 2017; J. Pauck[44], Interview 24, August 8, 2017; Prof. Sithole, Interview 26, August 9, 2017) referenced the important role PAMSA plays in this relationship. PAMSA coordinates activities between industry and academia, determining the type of research undertaken, accessing funding, and providing industry secondees into academia. Dr Pauck noted PAMSA's efforts to link education and industry as exceptional and unique to the sector (Interview 24, August 8, 2017).

This durable relationship indicates a collaboration in which industry and academics work very closely to update and inform each other's activities. This has created an environment of "knowing each other", whether people, capacity, experience or technical knowledge. Bouraoui et al. (2011) suggested interaction and collaboration between actors is more beneficial than

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[41] Prof. Bruce Sithole is a principal researcher and director of the Biorefinery Industry Development Facility at the CSIR in Durban. He is also a professor of Chemical Engineering at UKZN, Durban. His area of expertise is in biorefinery technologies and the valorisation of waste biomass.

[42] Mike Nash is the Director of PAMSA's Process Research Unit, which provides a platform for the pulp and paper industry to identify, fund and support post-graduate chemical engineering studies in the sector.

[43] Iain Kerr (now retired) was seconded by PAMSA as an honorary research fellow in Chemical Engineering at UKZN. His fields of expertise are pulp and paper making technology, water and effluent treatment, recycling and minimisation, cleaner production and resource efficiency, biorefinery technologies in the pulp and paper industry and nanocellulose.

[44] Dr Jimmy Pauck (now retired) held the position of Head of Programme: Pulp and Paper Technology in Chemical Engineering at the DUT. His subject expertise is in pulp and paper technology, process modelling and paper recycling.

acting alone. Such an alliance is therefore more than a network; it is also strategic and mutually beneficial, which are characteristics of a collaborative innovation network (Dodgson, 1994; Putnam, 1993; Schilling, 2015).

Another characteristic of the network is the significant and vital role played by national government in setting the county's bioeconomy agenda. Such policy and strategies provide the political context from which biorefineries and associated innovations can be supported via tax incentives, subsidies and state funding. While government has set up networks and platforms related to the bioeconomy, these tend to be disconnected and singular in focus, for example, biorefineries, biochar or alien vegetation. This is evident in the development of policies to support biorefinery R&D, or dialogues and strategies to enable the uptake of products such as biofuels and biochar. As an illustration of this disconnect, a dialogue on biochar, coordinated by the DEA (G Barnes, Interview 1, October 8 & 18, 2018) was held at the same time of year as the DST's announcement to establish a Biorefinery Research Consortium (Arnoldi, 2018). Neither government activity was aware of the other. To compound the issue of detachment, the latter was established without the knowledge of Prof. Godfrey[45] (Interview 25, October 19, 2018), who oversees the DST's South African Waste Research, Development and Innovation (RDI) roadmap (2018b). Such frustrations were witnessed regularly in interviews with leverage professionals reflecting on the challenges they faced when engaging with government departments, as illustrated below.

> "[E]ach department has a different mandate and you can have conversations with them individually, but they don't appear to connect amongst themselves very well." (Dr Morris[46], Interview 32, August 2, 2018).

> "[T]here are various [government] documents, bioeconomy strategies and research, but they don't really speak too much to each other. Various government departments are doing small things on the side and not really collaborating. In our interviews with government officials, they said it is a big problem and there hasn't been much

[45] Prof. Linda Godfrey is a principal researcher at the CSIR, and associate professor at North-West University. Her area of expertise is integrated waste management, with a research interest in the role the waste sector can have in transitioning South Africa to a green economy. She currently heads up the Waste Research Development and Innovation (RDI) Roadmap Implementation Unit on behalf of the DST.

[46] Dr Andrew Morris is the Chief Executive Officer of the ICFR, which is based at UKZN, Pietermaritzburg. At the time of interview, he also held the position of Acting Director. His areas of interest are in applied forestry research and sustainable forestry practices.

> collaboration. It's been very difficult, and if there are opposing views from different government departments, it halts industry from progressing." (B Deonarain[47], Interview 35, September 7, 2018).

Market formation is another motivating characteristic witnessed as needing collaboration. Market formation is a core function of a TIS (Bergek et al., 2008; Dewald & Truffer, 2011; Mazzucato, 2015) and as such, is discussed separately in Section 7.2.4.

7.1.3 Civil society and collaboration

As alluded to previously, civil society (in all its forms) is a key actor group in the quadruple helix innovation systems model. This grouping of organisations also represents, or indicates, the potential level of collaboration in the South African forestry-products biorefinery innovation system. As the adoption of a quadruple helix perspective is a core feature of this study, it was important to explore this dimension in depth to understand how and what civil society brings to the network.

In Figure 6, the civil society actors are denoted in lilac, with the leverage professionals interviewed representing six civil society organisations of varying types. According to the typologies of civil society actors by the WEF (2013) and the African Development Bank (2012), AfriBio, GreenCape, the Fetola Foundation, TIPS and WWF-SA are all classified as NGOs.[48] This means they have a formalised structure and are normally registered as such (African Development Bank, 2012; WEF, 2013). The outlier in this grouping is the SDCEA, which fits the profile of both a local grassroots- and a community-based coalition (African Development Bank, 2012; WEF, 2013). Other civil society actors mentioned by the leverage professionals included South Africa-based entities that have a strong advocacy, activist or environmental focus, such as Groundwork and the Wildlife and Environment Society of South Africa (WESSA). However, the majority of civil society actors cited by leverage professionals fit the profile of global governance and multi-national agencies. Examples are the Forestry Stewardship Council (FSC) and a number of United Nations programmes, including UNEP, the Industrial Development Organisation (UNIDO) and the Partnership for Action on Green

[47] Bhavna Deonarain, held the position of Researcher in Sustainable Growth at TIPS at the time of interview (she has subsequently moved on to another employer). She undertook research to inform a report (now published) on developing an action plan and implementation strategy for the biomaterials industry in South Africa (Montmasson-Clair et al., 2019).

[48] Also sometimes referred to as not-for-profit organisations (NPOs).

Economy (PAGE). The linkages with these agencies are predominantly through the funding of grants to undertake research, implement programmes and hold dialogues to leverage change.

Four NGOs I wish to highlight as core actors within the network are GreenCape, the SDCEA, TIPS and WWF-SA. While not the only civil society actors, they are singled out for being actively engaged with the forestry-products sector, yet from two different perspectives of inclusion.

The first is the SDCEA, which plays a dedicated environmental and social justice role in the South Durban basin. The basin is home to a cluster of chemical manufacturers and refineries, and Mondi and Sappi mills. The SDCEA contend that these industries contribute significantly to air pollution in the area (Firmin, 2019). This role aligns with NGOs that are classified as advocates, campaigners and activists (WEF, 2013). They provide societal pressure on others in an innovation system, oppose institutional dominance or advocate on behalf of a community (Ahrweiler et al., 2019; Geels & Urry, 2014; Penna & Geels, 2015; Veress, 2017).

Given this activist-focused role and their confined location of operation, the SDCEA appears in the network as being disconnected from the main activities. This is most likely due to the role they play as "watch dogs", taking industries in the basin to account for any environmental and social infringements. From the perspective of an enhanced collaborative TIS, the SDCEA's lack of position within the network is concerning. This is because an ideal innovation system's aim is to enhance the "economic well-being of disenfranchised members of society" (George et al., 2012, p. 663). These are the people whom the SDCEA represent. They are the voice of communities living within the shadow of the industries operating in the basin.

The SDCEA's external positioning may also be the result of a hostile relationship with industry, as noted by B Mthembu[49] (Interview 39, August 31, 2017) and Dr Pauck (Interview 24, August 8, 2017). This indicates a general lack of trust or willingness to cooperate, with accusations and judgement being common. From an industry perspective, Dr Heath[50] (Interview 12, October 15, 2018) of Forestry SA, noted they do engage with NGOs on environmentally focused

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[49] Bongani Mthembu works for the SDCEA as an air quality, geographical information system (GIS) and youth development officer. His role is to monitor and raise awareness of environmental justice and pollution transgressions associated with industry in the South Durban Industrial Basin. The SDCEA is based in the community that neighbours the heavy industrial area.

[50] Dr Ronald Heath is the Director of Research and Protection at Forestry SA. He coordinates and undertakes research for advocacy purposes on projects such as waste beneficiation and the market status of the industry.

projects. However, he stated that "although there is value working with them, sometimes it actually detracts from what you are trying to do, and there is conflict if you don't get anywhere." This finding is not unusual. Dunkley and Franklin (2017, p. 2) suggested having a localised *green identity* can have "a negative impact on wider community engagement with environmental projects".

On the other hand, and as an antithesis to the SDCEA's grassroots, community-responsive and campaigning role, GreenCape, TIPS, WWF-SA represent more formal larger-scale NGOs. They represent three different tiers of operation within the broader network – regional, national and multinational.

GreenCape is a provincial NGO. It was established with the mandate to grow the Western Cape Province's green economy by supporting businesses and investors. This is done through the identification of solutions to overcome eco-innovation challenges, such as the use of alien vegetation biomass to create biochar (GreenCape, 2020; Smout, 2020). To facilitate their ambitions, they have partnered with Wesgro to promote "tourism, trade and investment" within the province (J Lyons, Interview 37, October 19, 2018; Wesgro, 2020, para. 4), with J Lyons[51], the GreenCape leverage professional interviewed for this study, holding a liaison role between both entities.

Within the South African forestry-products biorefinery innovation system, GreenCape does not register as a central node (i.e., they were not identified by other leverage professionals within the system as a key contact point). This may be due to their regional scope and focus on traditional waste streams and alien vegetation, all of which would situate them outside current core biorefinery activity in the country. Based on this assessment, it can be argued that they fall within two civil society categories of agency, as advocates (WEF, 2013) for a green economy, and builders of business and government capacity (Cooper, 2018; WEF, 2013). They do this through the provision of knowledge and motivation to overcome green economy challenges. In addition, they can act as experts (WEF, 2013) by providing knowledge and guidance to shape policy, strategy and interventions.

GreenCape's position in the network, and jurisdiction of focus, is mirrored in the work of Muok and Kingiri (2015), who explored the role of civil society organisations in low-carbon

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[51] Jarrod Lyons is the Green Economy Investment and Finance Liaison at GreenCape and Wesgro. He is identified as a leverage professional exemplar. His profile is presented in detail in Chapter 9:, Section 9.4.

innovation in Kenya. Their reflections provide insight into why GreenCape is most likely to garner credibility and have agency. They suggested this is because the role of government as agent is overplayed, and the role of civil society in improving basic market economy institutions is often underestimated. They also suggested that civil society organisations are more flexible and often less bureaucratic than government agents and provide alternative pathways to sustainable futures.

The next NGO I wish to highlight is TIPS (Trade and Industrial Policy Strategies), a national economic research institution. TIPS support economic and policy development in the areas of trade and industry, sustainable growth and inequality and economic inclusion (TIPS, 2020). Some of their mechanisms for operating in the network include capacity building, knowledge sharing and dialogue facilitation. The latter two are of relevance to this study. It is through these routes that TIPS has undertaken research on developing a biomaterials strategy for South Africa. This was accompanied by stakeholder dialogue and the publication of a research report (see Montmasson-Clair et al., 2019). This piece of work was very much a collaborative exercise between TIPS and its research funding partners. These partners included various United Nations institutions, such as PAGE, the International Labour Organisation (ILO), the Development Programme (UNDP), UNIDO and the Institute for Training and Research (UNITAR). South African government partners included the national DEA, DTI and Economic Development (DED) (Montmasson-Clair et al., 2019). While this is an exhaustive list of partners, it illustrates how TIPS is connected within the South African forestry-products biorefinery and wider NIS. The connections are firstly, through partnerships created with large international invested multi-national NGO partners, notably the UN; secondly as advocates (Cooper, 2018; WEF, 2013), builders of capacity (Cooper, 2018) and trusted experts (through their research) (WEF, 2013); and thirdly, as coordinators of dialogue to foster knowledge exchange to catalyse South Africa's circular economy (Wood, 2018).

The approach of partnering with international and government departments is reflected in much of their work, for example, exploring regulatory burdens on small businesses (TIPS, 2017), and developing a case study on harnessing chemistry for sustainable development and female empowerment (Montmasson-Clair, 2019). This illustrates TIPS' centrality as an actor within South Africa's broader NIS. As such, it could be argued that a critique is required of its close relationships through funded partnerships with various government and international entities. This is because such relationships could create potential conflict, for example, being "caught increasingly between the business value system (efficiency, market needs) and their social mission (adherence to principles, ideological agendas)" (Ahrweiler et al., 2019, p. 29; Akrich & Miller, 2007; Ferretti & Pavone, 2009; Sutcliffe, 2011).

This discussion provides a lead into introducing the final NGO, WWF-SA. Their geographic remit and reach are explicit within its name –*World Wide* Fund for Nature. Consequently, it is both globally and locally recognised as being credible (Paul, 2002), trusted, admired (Anon., personal communication, 28 January 2020; WWF-SA, 2010) and well-connected (the latter indicated in Figure 6). However, at a granular level, while being a core actor within the *Waste to Wing* project, WWF-SA is not as connected or acknowledged as its broader national and international status would suggest. This is illustrated by having a small, and relatively siloed group of project partners. Notably the RSB (an international industry membership body), SkyNRG (an international sustainable aviation fuel solution provider) and the Fetola Foundation (a South African NGO that focuses on empowerment of small to medium enterprises [SMEs]). Links outside this confined network tend to be through one academic expert, Prof. Görgens (a leverage professional interviewed for this study) at Stellenbosch University.

While the *Waste to Wing* project has good intentions, it has found itself isolated within the broader South African forestry-products biorefinery innovation system. This is possibly because WWF-SA is at times criticised for operating independently without adequate recognition of work undertaken by others (Anon., personal communication, September 2018). This can lead to a duplication of work (A Williams, Interview 23, September 12, 2018). It was also suggested that this can result in a lack of clarity on WWF-SA's role and area of focus in the sustainability arena (Anon., personal communication, 10 February 2020). As with TIPS, the potential of being too influenced by its funders, instead of by the nature and people it represents, is also evident.

This criticism of WWF-SA, and of NGOs in general, is one that has been raised in the literature. Some authors, such as Matthews (2017) and Shivji (2007), suggest that neo-liberal policies have encouraged and enabled the escalating influence of NGOs over that of a diminishing state influence. This is exacerbated by influential NGOs (such as TIPS and WWF-SA), which are sometimes criticised for being more accountable to their funders (such as government or big business) and therefore defining project objectives in their favour. This as opposed to being accountable to their constituents (Banks et al., 2015; S. Drimie, personal communication, 6 February 2020; Matthews, 2017; Shivji, 2007). Other criticism is levelled when partnerships between NGOs and the private sector is too mutually involved or intimate, and therefore blurred and overlapping (WEF, 2013).

Therefore, in comparison to the SDCEA, it could be argued that TIPS and WWF-SA are distinguished as working within the system, while the SDCEA, with its activist role, is working against or outside it (Matthews, 2017). The latter exacerbates this divide through mechanisms of engagement that limit attempts to collaborate and build trust, such as conflictual stances to approaching issues. Accordingly, the general disconnection of civil society NGOs, and lack of integration or recognition is likely because industry, academia and research institutions do not consider the role civil society can play. When leverage professionals were asked whether they engaged with civil society, many stated they did not or did not do so readily (see P Saayman[52], Interview 18, August 7, 2018; I Kerr, Interview 31, August 8, 2018; M Nash, Interview 15, September 6, 2018; and Dr de Graaf[53], Interview 10, September 6, 2018). This is explored further in Chapter 8.

Based on the above discussion, it could be concluded that civil society organisations, while represented as nodes in the network (see Figure 6), are not significant role players in comparison to other prominent academic and industry actors in the system. While this is suggested, it should be noted that their lack of significant integration is not a reflection of their ambitions. They have the desire to catalyse markets to transition towards a green economy or to challenge the way the sector does business. This assessment therefore clearly demonstrates civil society is not as integrated into the South African forestry-products biorefinery innovation system as it should be. This refers to the quadruple helix model, which calls for civil society as a legitimate and prominent stakeholder in an innovation system or process (Bornmann, 2013; Carayannis & Campbell, 2009; Caruso, 2018; Martin, 2011; Steenkamp, 2019).

7.1.4 Value chain differentiation

Value chain differentiation is a prominent structural characteristic identified in the TIS. The forestry-products sector is well defined, with a well-established history and structure (as

[52] Petrus Saayman is Operations Director for Evergreen Timbers, a timber mill in KwaZulu-Natal. His interests lie in identifying opportunities to use wood residue and sawdust generated during the milling process to produce higher-value-added products.

[53] Dr Johan de Graaf is an executive manager at Hans Merensky Holdings. He focuses on adding value to the business through R&D, and environment and forestry planning. He coordinates the relationship between Hans Merensky Holdings and Prof. Sithole at the CSIR's biorefinery industry development facility.

outlined in Chapter 2). However, given that alien vegetation is generally not considered in the forestry-products value chain, the wider biomass value chain could be strengthened and benefit from its incorporation. This could be done by combining their respective intentions and efforts to add value to biomass.

Interestingly, this differentiation of value chains is considered a characteristic of a mature TIS. A mature TIS is also characterised as being more stable, with a high degree of specialisation and many beneficiaries (Markard, 2018).

An assessment of the regulations, standards and value chain differentiation characteristics of the network suggests they are lacking, incoherent and disconnected in the South African forestry-products biorefinery innovation system. This may be due to the lack of coherent and specific policies or to disconnected activities and siloed networks.

What is evident from the analysis is that the biorefinery network is characterised by quasi-formality. It has no central forum or lead actor and has networks within networks (intra-networks). These develop organically based on a "needs must", political agenda or historical relationships basis. A similar finding was raised by Bauer et al. (2018) in their work on the dynamics of the Swedish biorefinery innovation network. Their research suggested that inter-sectoral collaboration is less favoured than intra-sectoral collaboration. They indicated one of the likely reasons for their finding is the level of trust. This is because actors are more likely to collaborate with those with whom they have a previous or indirect relationship. This element of trust is pivotal to the concept of social capital and is explored further in Chapter 8.

While intra-networks exist within the South African biorefinery innovation system, some form of alignment is emerging within the system. This rudimentary structuring of the network is considered by TIS authors (Bergek et al., 2008; Markard, 2018; Musiolik et al., 2012; Negro, 2007) as illustrative of a TIS in its formative or transitioning to growth phase.

7.2 Functionality of the biorefinery innovation system

It has been said that functions are processes that are important for a TIS to perform well (Hekkert et al., 2007). Each function should occur within and contribute towards the overall functioning and performance of the innovation system (Bergek et al., 2008; Hekkert et al., 2007; Negro, 2007; Uriona & Vaz, 2017). Various function lists have been produced to determine the productivity of a TIS (Bergek et al., 2008; Bergek et al., 2010; Hekkert et al., 2007; Johnson, 1998; Uriona & Vaz, 2017; Walz et al., 2016). Drawing on these, the following functions will be assessed to explore the functionality and productivity of the South African forestry-products biorefinery innovation system:

1. Knowledge generation and diffusion through networks
2. Influence on the direction of research
3. Entrepreneurial activities and experimentation
4. Market formation
5. Legitimisation of biorefinery technologies
6. Resource mobilisation

This assessment sets a platform for determining how far the TIS has progressed, how far it needs to progress, and how it could operate effectively to increase the uptake of biorefinery technologies in the South African forestry-products sector.

7.2.1 Knowledge generation and diffusion

This function covers how learning takes place within a TIS, using R&D as an indicator of knowledge development (Hekkert et al., 2007; Uriona & Vaz, 2017). In terms of knowledge diffusion, this encompasses how knowledge is exchanged and diffused in the system. At a basic level, this includes the number of workshops or conferences attended by individuals within the network (Coenen, 2010; Hekkert et al., 2007; Uriona & Vaz, 2017). Given that the knowledge network, and knowledge generation and diffusion are key areas of emphasis for this study, this indicator is deemed too minimalist and quantitative. For this reason, I explore this function separately in Chapter 8.

7.2.2 Influence of the direction of the research

This function assesses the type of research that is being undertaken within a TIS. The influential drivers stimulating a diversity of technology and product R&D are investigated. This is based on the notion that over time a more dominant, contextually feasible technology should emerge from the initial diversity of technologies (Walz et al., 2016).

Dr Maseko[54] (Interview 38, September 20, 2018) of AfricaBio noted there are a number of biorefinery R&D initiatives underway in the country. In his view, South Africa is "punching above our weight" as leaders in biorefinery R&D. He believed this is due to the dedicated years of focused R&D programmes. In the main, biorefinery R&D in the country is undertaken by industry, academia and research institutions. In the case of industry, this is spearheaded by Sappi. They emerged as the country's biorefinery industry leaders, and were regularly named by the leverage professionals as such (notably A Baldo, Interview 9, October 15, 2018; Dr de Graaf, Interview 10, September 6, 2018; Prof. Görgens,[55] Interview, 29, September 8, 2018; S Kalan,[56] Interview 3, September 5, 2018; Dr Längin,[57] Interview 14, August 6, 2018; M Nash, Interview 15, September 6, 2018; S Ngubane,[58] Interview 4, August 2, 2018; M Peter,[59] Interview 16, September 5, 2018; P Saayman, Interview 18, August 7, 2018; Dr Sefara,[60] Interview 19, September 3, 2018; Prof. Sithole, Interview 27, August 1, 2018; R Southey,[61] Interview 20, September 19, 2018; and J-P van der Merwe,[62] Interview 22, September 25, 2018).

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[54] Dr Bongani Maseko is a general manager overseeing Agricultural Biotechnology at AfricaBio. He is responsible for the management of outreach, communication and capacity building initiatives designed to promote the safe and responsible use of biotechnology in South Africa and other African countries. He has a strong background in forestry science and protection.

[55] Prof. Johann Görgens is a senior lecturer and the Director of the Centre for Process Engineering in the Department of Chemical Engineering, Stellenbosch University. His research experience is in renewable energy, which includes cultivation processes for ethanol production from plant biomass, process modelling and the economic evaluation of renewable energy technologies in South Africa.

[56] Sunita Kalan is the Director of Sector and Local Innovation in the DST, which falls under the Chief Directorate of Sector Innovation and Green Economy. Her role is to strengthen the NIS to enhance economic growth.

[57] Dr Dirk Längin is the Forest Re-Engineering Manager at Mondi SA. His interests are in forestry engineering and re-engineering, which includes harvesting, logistics and R&D.

[58] Steven Ngubane is a senior project manager, Agro-processing and Agriculture, in the IDC. His area of specialism is forestry. Before working at the IDC, he worked at Forestry SA as a Business Development Director.

[59] Michael Peter is the Executive Director of Forestry SA. His role involves advocacy and lobbying on behalf of South Africa's forestry sector. He is involved in the development of national standards, policy and legislation, and participation in domestic and international forest sector dialogues.

[60] Dr Nelson Sefara is the General Manager of Sappi's Technology Centre in Pretoria. The areas of expertise at the centre include the provision of analytical chemical science and biochemistry support to Sappi's mills, and environmental research into sustainable solutions for pulp and paper mill water and product waste, which include biorefineries.

[61] Roy Southey is the Executive Director of Sawmilling SA. His role is to promote the interests of small and large sawmillers in South Africa and to lobby government.

[62] Jaco-Pierre van der Merwe is a wood technologist at York Timbers. Within his portfolio is R&D on added-value products, for which biorefineries are an option.

Sappi's focus has been driven by the company's ambition to diversify its product portfolio, which has traditionally focused on pulp and paper production. However, it is shifting its focus towards increased production of DWP[63] and opportunities such as nanocellulose, biorefinery products and energy (Sappi, 2018a). Sappi's first foray into biorefinery R&D was through their collaboration with Borregaard LignoTech (50% owned by Sappi) (H Reddy,[64] Interview 17, August 6, 2018). Through this collaboration, Sappi is able to add financial value to its pulp operations by using byproduct to generate high-value lignosulfonate (H Reddy, Interview 17, August 6, 2018). Sappi continues to invest in R&D and new technologies to meet its ambitions. For example, in 2017, it acquired clean-up technologies, Xylex® and Versalac® (including patents, knowledge, equipment and key technical staff from the owner company, Plaxica Limited). Sappi also invested in a demonstration unit at its Ngodwana Mill to extract sugars from pulp (Sappi, 2016, 2017, 2018b). Its R&D initiatives are supported through a dedicated biorefinery R&D centre, based in Pretoria, which also serves its global operations. It functions as a centre of excellence for pulping, bleaching and stock operations (including coating applications and bio-composites) (Dr Sefara, Interview 19, September 3, 2018).

To date, no other major industry actor has invested or implemented biorefinery technologies in South Africa on the same scale as Sappi. Mondi has adopted a *wait-and-see* approach, with a focus on re-engineering initiatives (Dr Längin, Interview 14, August 6, 2018). Hans Merensky, on the other hand, has begun to explore opportunities with the CSIR's Biorefinery Industry Development Facility (Dr de Graaf, Interview 10, September 6, 2018). It could be suggested that this lack of investment is due to the large amount of capital expenditure required to undertake R&D, construct and operate the large-scale activities Sappi undertakes (B Deonarain, Interview 35, September 7, 2018; Dr Kanzler[65], Interview 13, August 7, 2018; Dr Sefara, Interview 19, September 3, 2018). It may also be due to the *closed* nature of Sappi's R&D model, which aims to undertake R&D to develop in-house knowledge and capacity to enhance

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[63] DWP is a high-grade cellulose pulp with low contents of hemicellulose, lignin and resin. It can be used as a supplement in the manufacturing of food, drinks, textiles, pulp and paper, and ethanol (Bajpai, 2014).

[64] Henry Reddy is the Technical Services Manager at LignoTech South Africa. He is involved in R&D, IP, environmental and quality control, customer technical queries and provides operational support. LignoTech is a biorefinery operation producing lignin-based products from byproducts produced at Sappi's Saiccor Mill in Umkomaas, KwaZulu-Natal.

[65] Dr Arnulf Kanzler is the Programme Leader for Tree Breeding at Sappi's Shaw Research Centre in KwaZulu-Natal. He leads their research on tree species and their adaptation to pests and diseases in South Africa's growing conditions. His interests are in breeding trees for sustainability, resource management and conservation.

the company's competitive advantage. This was captured by Dr Sefara (Interview 19, September 3, 2018). He noted:

> "We're a public company but obviously this Research and Development Centre is for Sappi. There is certain development work that is done here that is done exclusively in-house. It is not leveraging on any other capabilities outside Sappi because we're basically intentionally wanting to do it that way. It keeps this muddy space around who owns what."

Two of the leverage professionals interviewed commented on the impact this has in the network. They also suggested why Sappi is likely to be adopting such an approach.

> "So now we have to do research that does not get up Sappi's nose, because they are funding their own research for their own IP to develop their leading-edge technology, so we can't do anything with them." (Anonymous).

> "For someone like Sappi, I can fully understand that it is a competitive space. They're a new entrant into furfural, xylitol and nanocellulose. They need to carve a role for themselves where they can maintain a competitive advantage." (Prof. Görgens, Interview 29, September 8, 2018)

Such an approach could be considered a hindrance to biorefinery technology uptake in the sector. Therefore, a more *open* network of knowledge sharing is deemed a prerequisite for enhanced uptake and innovation (Barnard & Chaminade, 2017; de Oliveira et al., 2017). Chesbrough (2006) criticised the adoption of closed innovation. He noted that, while there are plenty of ideas, they are not shared. This is because there is a perception that ideas need to be controlled and internally focused. Such a process, Chesbrough argued, dominated most of the twentieth century. However, with ever-increasing time to deliver products to market, and increasingly more well-informed consumer and suppliers, innovations were being challenged. Chesbrough proposed the concept of "open innovation", which means firms can and should integrate internal and external ideas and knowledge from beyond the firm (Chesbrough, 2006, p. 4; Savory & Fortune, 2015). The issue of open and closed innovation from a knowledge exchange perspective is explored further in Chapters 5 and 8.

The second area of R&D activity identified within the biorefinery innovation system is that undertaken by the CSIR and other academic institutions. The CSIR is seen as one of the main actors catalysing and driving R&D in this area, notably through the establishment in 2017 of the “world-class” Biorefinery Industry Development Facility funded by the DST (Sithole, 2017a, p. 16). The aim of the facility is to demonstrate the feasibility of biorefinery technologies. It also aims to illustrate the type of high-value products that can be manufactured from forestry-products residue, such as sawdust and fibre residues (Prof. Sithole, Interview 26, August 12, 2017). The facility’s current emphasis is hemicellulose sugars, pine oils and nanocrystalline cellulose (Sithole, 2017a). R&D activities undertaken by the facility are supported by other CSIR in-house expertise, for example, cost-benefit analyses and techno-economic feasibility assessments for forestry products and alien vegetation (see Stafford, 2017; Stafford et al., 2016). This research is widely cited by the South African sustainability and environmental research community. It is used to validate and argue for how jobs can be unlocked, and financial value realised through the industrial symbiosis of biomass (see Jenkin & Mudombi, 2018; Rashamuse, 2018; TIPS, 2019). The influential drivers catalysing the investment in the CSIR’s activities have come predominantly from the South African government, through the auspices of the DST. The main reason given by the DST for funding the CSIR, and other biorefinery activities, was the need to enable a transition towards a green economy (SA Government, 2018a). The funding of the facility is one of a number of responses to a range of policy mechanisms, such as the *Biofuel industrial strategy* (SA Department of Minerals and Energy, 2007), the *Bioeconomy strategy* (SA Department of Science and Technology, 2013), the *Green economy accord* (SA Department of Economic Development, 2011) and the *National development plan: Vision for 2030* (National Planning Commission, 2011).

While the CSIR’s biorefinery R&D initiatives are relatively new, a few South African universities have been active in the biorefinery arena for a longer. Notable are the North-West University (cereal- and meat-derived wastes), Stellenbosch University (sugarcane, forestry-products-, fruit and vegetable- and fish-derived wastes), and the University of Cape Town (wastewater, confectionary wastes and bioprocessing) (Centre for Renewable and Sustainable Energy Studies [CRSES], 2019; SA Department of Science and Technology, 2018b; Future Water, 2019; Prof. Görgens, Interview, 29, September 8, 2018; Koch, 2018; Nicolson, 2018). For a full list of research undertaken, see Appendix E.

What is evident from the analysis, is that most forestry-products biorefinery research is conducted at Stellenbosch University and the CSIR, the latter through a collaborative partnership with the Department of Chemical Engineering at the University of KwaZulu-Natal

(UKZN). In addition, the list of research highlights the dominance of techno-economic focused research, which, as stated by Prof. Görgens (Interview 29, September 8, 2018), could be problematic. He noted that this focus tends to negate the social value of biorefinery innovations. It also neglects other dynamics, such as knowledge development, human resource capacity and governance. This statement was echoed by Hausknost and Haas (2019) in their paper *Politics of selection: Towards a transformative model of environmental innovation*. They suggested that dominant discourses[66] in the field of environmental innovation are focused on market-driven processes. As such, they argued, these discourses neglect societal goals and sustainability.

The leverage professionals spearheading R&D, and catalysing change for increased uptake of biorefinery technologies are investigated in more depth in Chapter 9.

7.2.3 Entrepreneurial activities and experimentation

The role of entrepreneurs, new entrants or established actors, wanting to diversify in a TIS is an important function. It illustrates interest in the opportunities and possibilities that could be realised through a technical innovation. In addition, an assessment of the diversity of technologies and products being explored or implemented by actors is considered vital to the sufficiency and proficiency of the system. Doing so enables market opportunities to be realised (Bergek et al., 2010; Hekkert et al., 2007). Walz et al. (2016, p. 4) argued that activity diversity ensures there is a "large stock of technologies enabling the selection process to result in a dominant design."

Forestry-products biorefinery entrepreneurial activities in South Africa are not as diverse or as advanced as they could be. This is predominantly due to three factors: first, much of the focus to date has been on R&D, with little transition from R&D to commercialisation; second, there has been an emphasis on a select few products; and third, there has been domination by Sappi. This was well articulated by Prof. Görgens (Interview 29, September 8, 2018), of Stellenbosch University, who noted:

> "For me the real innovation comes when you start looking at other products. For those other products the markets are even more fickle than for the more established products. I've got a marketing report where they identified forty-six chemicals where there is

[66] These dominant discourses relate to the multi-level perspective (MLP) on socio-technical transitions, the IS approach, and the long-wave theory (LWT) of techno-economic paradigm shifts (Hausknost & Haas, 2019).

some form of international activity. … right now, most people [in South Africa] seem to be thinking about ten products when they talk about biorefineries. There’s actually a big difference between these. If the world really moves towards sustainability, then we’re going to get closer and closer to these forty-six products eventually.”

The lack of entrepreneurial activity at the small to medium scale was particularly notable. Only two start-ups were identified for this study, DalinYebo and the eThala Group. This is a concern. It means the government’s emphasis on R&D as a catalyst for green economic transformation has caused little entrepreneurial activity to materialise from such investment. Whether R&D should be seen as a mechanism for growing an economy has been debated. For example, Demirel and Mazzucato (2012) suggested that R&D can enable small firm growth if done in conjunction with a high degree of patenting by a firm.

In terms of entrepreneurial activity and alien vegetation, the situation is more dynamic, with many actors. However, the focus tends to be on lower-value products, such as firewood, charcoal and biochar, wood chips and pellets (G Barnes, Interview 1, October 8 & 18, 2018; Jenkin & Mudombi, 2018; Stafford, 2017; Stafford et al., 2016; G Trebble[67], Interview 21, August 20, 2018). These activities range in scale from small initiatives, such as localised contractors harvesting firewood, through to the IDC’s multi-million Rand investment in wood pellet manufacture (Jenkin & Mudombi, 2018; S Ngubane, Interview 4, August 2, 2018). Yet it was recognised that alien vegetation biomass is suitable for processing into higher value biorefinery products. With the volumes available, this could be a significant area of opportunity (Prof.. Sithole, Interview 26, August 9, 2017; Stafford, 2017; A Williams, 2014, Interview 23, September 12, 2018).

What is apparent from this analysis is that, while similar biorefinery opportunities exist for the forestry-products and alien vegetation sectors, they seldom collaborate or exchange knowledge. Both sectors, in the main, continue to operate separately. For example, the work of the CSIR’s Biorefinery Industry Development Facility, Stellenbosch University, and the DST’s financial

[67] Grant Trebble operates independently in the alien vegetation sector. For many years, he coordinated the DEA’s Expanded Public Works Programme (EPWP), overseeing operations in the Free State and KwaZulu-Natal to manufacture furniture from alien vegetation. He continues to be involved in the sector as an advisor in the biomass added-value space.

support tends to focus on the forestry-products sector, while the IDC, small-to-medium enterprises, and the DEA tend to focus on alien vegetation opportunities.

The role of SMEs is an important consideration within entrepreneurial and transitioning to a green economy discourse, even if not explicitly recognised in TIS literature. This was highlighted by P Saayman (Interview 18, August 7, 2018), of Evergreen Timbers, who noted that "I know it's natural they [the CSIR] are close with Sappi and big corporates at the moment, but I think they need to involve the smaller guys. … and show them the future potential of biorefineries."

In South Africa, entrepreneurial activities are seen to play a pivotal role in the national economy. They are promoted as creators of jobs, able to lift people out of poverty and improve livelihoods (Clarke, 2018; SA Department of Minerals and Energy, 2007; McLean, 2018; National Planning Commission, 2011; S Ngubane, Interview 4, August 2, 2018; SME South Africa [SMESA], 2018). This is particularly the case for biorefinery potential associated with downstream activities in the forestry-products value chain. This is because most tree plantations and clusters of alien vegetation are located in rural areas (Dr de Graaf, Interview 10, September 6, 2018; Forestry Economic Services, 2018; Dr Rashamuse[68], Interview 7, September 5, 2018). It is in these rural areas that approximately 40% of South Africa's poorest live (Statistics SA, 2018b). Decentralised biorefinery activities, such as part-processing, in rural areas are therefore considered real opportunities to improve livelihoods. They can also provide added value opportunities for SME sawmills, who are increasingly facing economic strain. This was noted by several leverage professionals:

> "The idea is, and of course it will have its challenges, to have an intermediary product that some SMEs may develop, that may convert some of that lower-value product at the sawmill that we can then transport to a centralised bioenergy or biorefinery facilities." (Dr de Graaf, Interview 10, September 6, 2018)

> "[W]hat emerged is the sheer potential, because of sawmilling's byproducts volumes produced. You can extract all the things Bruce [Sithole] is doing, and that has positive implications in rural areas, and you can do it small. Nelson Sefara at Sappi suggested it

[68] Dr Konanani Rashamuse is the Director of Industry and Environments at the DST. He was instrumental in developing South Africa's bioeconomy strategy.

[biorefineries] can only ever be big, and I hesitate to debate that. But you know, in South Africa, that's kind of what we need." (S Kalan, Interview 3, September 5, 2018)

> "[W]e don't want to export all of our jobs to Gauteng or KZN or Cape Town. If we can create value and livelihood opportunities in rural areas then that would be first prize." (Prof. Godfrey, Interview 25, October 19, 2018)

> "[T]he project [*Waste to Wing*] is going to look at how small enterprises can be empowered in these [biorefinery] industries. So not only looking at working with the big players, but also with small enterprises." (A Baldo, Interview 9, October 15, 2018)

While these SME opportunities exist and are recognised, there are challenges, notably capital investment, knowledge and experience, capacity and skills – as S Kalan (Interview 3, September 5, 2018) of the DST noted, "they forget to do basic business stuff, and then it's also costly."

Because of these issues, yet also the potential, the CSIR (with funding from National Treasury) put out a call to fund SME and municipal R&D forestry-products biorefinery opportunities (Prof. Sithole, personal communication, April 4, 2019). At the same time, but separately, the Fetola Foundation put out a call, under the *Waste to Wing* project, for SMEs to apply for funding to convert biomass to energy. This included biofuel (Fetola Foundation, 2019b).

Another dimension to this discussion is whether biorefinery technologies should be imported into, adapted or manufactured in South Africa, as outlined below.

1. *To import and exploit technologies developed outside the country* – for example Sappi's purchase of clean-up technology. This included the purchase of know-how and expertise from the parent company (Sappi, 2017).
2. *To adopt, yet adapt, externally developed technologies to suit the South African context* – in some instances, playing catch-up or *leapfrogging* international innovation initiatives (Canuto, 2018; Ekasi Energy, personal communication, 28 January 2018; A Williams, 2014). This view is supported by Manzini (2015) in his paper on the measurement of the NIS in South Africa.
3. *For South Africa to research, develop, design and implement its own technologies.* Some of which could be reversed, that is, exported to developed countries (Stainsack & Forterre, 2015). This would be the case with Sappi's R&D Biorefinery Centre of

> Excellence exporting their technology and know-how into their global value chain (Dr Sefara, Interview 19, September 3, 2018).

This question of approach was raised by Prof. Görgens (Interview 29, September 8, 2018), of Stellenbosch University, who wondered which approach would emerge from this study as the most favoured. In this regard, the second – to adopt and adapt – was deemed the most appropriate and recognised business model in some leverage professional interviews (Sehgal, 2018; G Trebble, Interview 21, August 20, 2018). Discourse on the introduction of technologies is reflected in innovation and entrepreneurial literature, particularly from the perspective of developing economies. For example, see Canuto (2018), Fatima (2017), Stainsack and Forterre (2015) and Tolentino (2017).

7.2.4 Market formation

Ideally, this function alludes to the provision of a secure and conducive niche environment for the development of new technologies and products. This niche is supported through incentivised mechanisms (such as tax and standards) to stimulate and expand a market (Bergek et al., 2008; Hekkert et al., 2007; Markard, 2018; Negro, 2007; Uriona & Vaz, 2017). Mazzucato (2015, p. 3) suggested that "innovation-led growth … requires the shaping and creating of markets." This function also explores the technology or product demand through mechanisms such as research, pilots or demonstration projects (Bergek et al., 2008; Coenen, 2010).

While policy, strategy and individual projects exist, no formal, secure or conducive environment was identified in South Africa for biorefineries in the forestry-products sector. This is reflected in the disparate activities, which are predominantly driven by industry, government departments or NGOs areas of interest.

Aside from the DST's financial commitment to the CSIR, the *Waste to Wing* project, and TIPS' development of a biomaterials action plan, no other forestry-products biorefinery market incentivisation initiatives were identified. While policy does exist to support market formulation, it is disparate and tends to focus on supporting government areas of emphasis. For example, there was a focus on biofuels (SA Department of Minerals and Energy, 2007; DoE, 2014; Williams, 2014; WWF-SA, 2019), and bioenergy (Beekes et al., 2014; (SA Department of Science and Technology, 2015; GreenCape, 2017; Honsbein, 2014; Mavuso, 2017; Pelkamans & Bali, 2018). The latter emphasised agricultural sources (such as maize, sugarcane and oilseed) as feedstock, as opposed to forestry, forestry-products and alien vegetation biomass and residue.

The emphasis on agricultural feedstock is contentious, as noted by WWF-SA (2019), which raised a concern about crop-based fuels competing with and displacing food crops. This is of most concern in a country such as South Africa, where an estimated 26% of households go hungry (Human Sciences Research Council [HSRC] & South African Medical Research Council [MRC], 2013). This is a good example of how an NGO can play a role as critic of the *status quo*, choices and ideas generated in an innovation system (Matthews, 2017).

Industry, while seeking market support, has spearheaded and funded their own market-based initiatives (Dr Sefara, Interview 19, September 3, 2018; A Williams[69], Interview 23, September 12, 2018). In the case of Citius Energy, A Williams (Interview 23, September 12, 2018) noted this meant side-stepping government bureaucracy. He suggested working in the private space enabled them to mitigate this and move around prohibitive legislation "to get the job done." Or, in the case of Ekasi Energy, the founder invested their own finances to develop an alien vegetation biomass pellet and clean-energy cook stove (Ekasi Energy, personal communication, 28 January 2018). It was also suggested that the reason business self-invests is that banks are unfamiliar with smaller-scale biorefinery business models and practices, and so are unwilling to take risks in the unknown (Jenkin, 2018; Jenkin & Mudombi, 2018). In the case of Sappi, it has gone beyond South Africa's borders to seek markets for its products.

The notion of seeking an international market is the default paradigm for many biorefinery products manufactured in South Africa. Wood pellet production from alien vegetation is a good example of this. Investments were focused on establishing large-scale, centralised processing and manufacturing plants for the international market. This was seen by some as problematic (Jenkin & Mudombi, 2018; S Kalan, Interview 3, September 5, 2018; Dr Längin, Interview 14, August 6, 2018; G Trebble, Interview 21, August 20, 2018), because a number of these initiatives have failed. For example, the IDC's significant investment in two biomass pellet manufacturing plants, which closed in 2015 (Odendaal, 2015).

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[69] Anthony Williams is Managing Director of Citius Energy, and Chief Operational Officer of the Toronto Group. His main areas of expertise are energy policy and strategy and project development, with an emphasis on renewable energy and bioenergy.

This large-scale-centric model is to the detriment of a decentralised entrepreneurial model, which could aim to transition to a larger-scale business model by adopting well-informed and contextually feasible technologies (Markard, 2018; Musiolik et al., 2012). Consequently, the model either leads to a monopoly of practice (as is the case with Sappi) or failure (as with the IDC's wood pellet initiative). It was therefore suggested that incentivisation to aid market-led smaller niche decentralised activities would be more appropriate for South Africa's forestry-products biorefinery innovation system (A Dinan[70], Interview 34, August 31, 2018; Jenkin & Mudombi, 2018; G Trebble, Interview 21, August 20, 2018; A Williams, Interview 23, September 12, 2018).

It has been said that one of the reasons for commercial failure or poor technology attrition is the lack of adequate or appropriate market research prior to investment and implementation (B Deonarain, Interview 35, September 7, 2018; Herstatt, 2004; Jenkin & Mudombi, 2018; K. Ross[71], Interview 8, September 4, 2018; Washington, 2013). Chiesa and Frattini (2011) noted in their paper *Commercialising technological innovation* that this phase of the innovation process is one of the least managed. It should incorporate how actors in the system can be encouraged to adopt the innovation; and for early adopters to disseminate the positive and negative benefits of the innovation. In their interviews, this lack of market understanding was recognised as a challenge by Prof. Görgens, (Interview 29, September 8, 2018), G Trebble (Interview 21, August 20, 2018) and A Williams (Interview 23, September 12, 2018). Therefore, the need to be more commercially realistic, and to better articulate the benefits of biorefinery opportunities (Jenkin, 2018) needs to be better articulated. As suggested below:

> "From what I see, we and the market lack biorefinery products, and getting people to change their mindsets. Showing them the possibilities and not marketing these little fluffy pictures but physically going out and developing the business sector. What we

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[70] At the time of interview, Amanda Dinan held the role of Green Economy Lead at the Fetola Foundation, a project partner in the *Waste to Wing* project. Amanda's expertise is in socially responsible investment funds, including carbon finance, impact investing and resource economics.

[71] Kira Ross, at the time of interview, held the position of Senior Manager: Business Optimisation and Special Projects at SAFCOL. She has subsequently been promoted to Acting Executive: Strategy, Innovation and Marketing. Her role includes the development and implementation of strategic plans for the implementation of new and existing products or initiatives.

lack is marketing and business development expertise." (C Smit[72], Interview 8, September 4, 2018)

This statement was supported by his colleague, K Ross (Interview 8, September 4, 2018). She noted "you can produce a product, but, unless people see the value in it, you're not going to sell it."

J Lyons (Interview 37, October 19, 2018) of GreenCape, went a step further. He suggested that South Africa does not have a cohesive countrywide feasibility study for biorefineries. He did note the country has a *Biomass atlas* but suggested "it is not enough information for a multinational to make the move [invest]." As noted earlier, several techno-economic studies on biorefinery potential do exist for the country, but what was being suggested by J Lyons was that these do not adequately cover market feasibility. An example of where the feasibility of biorefinery technologies is being explored is at the CSIR's Biorefinery Industry Development Facility. Here, much of the work undertaken focuses on identifying and demonstrating technical solutions (SA Department of Science and Technology, 2018a, 2018b; Prof. Sithole, Interviews 26 & 27, August 9, 2017, August 1, 2018; Dr Trotter[73], Interview 28, August 1, 2018). This demonstration practice is combined with that of colleagues from other CSIR departments who specialise in economic and cost-benefit research (for example, Stafford, 2017; Stafford et al., 2016, 2019). This type of work perpetuates the techno-economics of much of the research work undertaken in South Africa. It emphasises the economic potential of a proposed technical solution (Rao, 2012), as opposed to an approach that assesses market need or acceptance. The market-led approach, combined with the techno-economic solution, may elicit the formation of a more multi-dimensional market for biorefinery technologies in the country. This would provide the basis from which more "fit-for-purpose" technologies and products gained traction within the forestry-products sector. This could enable a transition towards larger-scale acceptance of biorefinery technologies and products.

Three clear examples of how civil society is playing a role in advocating for biorefinery market formation include the *Waste to Wing* project, the DEA's biochar knowledge network, and TIPS'

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[72] Christiaan Smit is a wood and lumber specialist at SAFCOL. He works closely with Kira Ross to assess added value potential from SAFCOL's plantation and sawmilling operations, of which biorefineries are an option.

[73] Dr Douglas Trotter holds the position of Competency Area Manager for Green Economy Solutions and is also the research group leader for the Sustainability, Science and Resource Economics team at the CSIR in Durban. His main areas of interest are sustainability planning, environmental management and pollution ecology.

biomaterials action plan. *Waste to Wing* is a collaboration between WWF-SA, RSB, the Fetola Foundation and SkyNRG[74]. The aim of the initiative is to undertake a feasibility study and trial the use of aviation biofuels in South Africa (Fetola Foundation, 2019a; WWF-SA, 2018, 2019). The project sets the platform and potential to inform policy and encourage commercial use of aviation fuel in the country (T Bole-Rentel[75], Interview 33, August 31, 2018; WWF-SA, 2019).

Another example of an attempt to activate a market is the biochar knowledge network initiated and coordinated by the DEA. The network aims to enhance collective knowledge to stimulate the biochar market and biomass economy, and to overcome barriers to market entry (G Barnes, personal communication, September 3, 2018).

The TIPS example illustrates how international funded dialogue and research aims to stimulate South Africa's biomaterials sector by providing strategic policy guidance and an action plan (Montmasson-Claire et al., 2019).

All three initiatives aim to harness and advocate the potential of biomass, which in turn drives the ambitions and outcomes of the respective networks and dialogues. For the former, it is the production and ultimate use of biofuels for the aviation sector. For the DEA and TIPS, it is to unlock the economic and environmental potential of adding value to alien vegetation and biomass residue.

The analysis of the biorefinery market suggests a non-cohesive and poor-market approach to the formation of a forestry-products biorefinery and associated product market in South Africa. Dr Morris (Interview 32, August 2, 2018), of the Institute for Commercial Forestry Research (ICFR), went so far as to suggest it was "scatter-gun". Some have suggested this is due to inadequate funding, no coordinated forum, a lack of long-term planning, siloed practices, and weak procurement specifications or legislation (Jenkin, 2018; A Baldo, Interview 9, October 15, 2018; Dr Kanzlar, Interview 13, August 7, 2018; Dr Morris, Interview 32, August 2, 2018; A Williams, Interview 23, September 12, 2018).

With regard to standards and legislation, J Lyons (Interview 37, October 19, 2018), of GreenCape, in his interview suggested that:

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[74] SkyNRG is a global leader in sustainable aviation fuel (SkyNRG, 2020).

[75] Tjaša Bole-Rentel is the Bioenergy Project Manager in WWF-SA's Policy and Futures Unit. She co-ordinates and undertakes research to support the *Waste to Wing* biofuels project.

> "[F]or bioethanol to become a reality, the DoE needs to designate the mandatory blending of biofuel into traditional petroleum fuel. The minute that happens, I will get multiple calls from multinationals that are able to convert cellulose into ethanol. But everybody is standing at the door waiting for that type of legislation to happen, so it probably won't happen."

In relation to this, while South Africa has a *Biofuels industrial strategy* (SA Department of Minerals and Energy, 2007), and a *Draft position paper on the South African biofuels regulatory framework* (SA Department of Energy, 2014), there has been little shift in increased uptake of biofuels. Reasons given for this lack of movement included technology, conversion process and feedstock challenges (Blanchard et al., 2011), manufacturing capacity and commercial viability (Burger, 2014), as well as poor public/private partnership support, investment in renewable energy (Martin & Movundlela, 2019), and the government's continued subsidisation of coal-fired power (Burton et al., 2018; ODI, 2019).

7.2.5 Legitimisation of biorefinery technologies

Within the TIS framework, the function of legitimisation is determined by a coalition or collaborative group or groups of actors. They promote, support or defend new technologies, and recognise the potential for certain technologies (Hekkert et al., 2007; Uriona & Vaz, 2017). These actors may counteract or inhibit the implementation of strategy and development efforts. Resistance may be in the form of political policy which does not adhere to the group(s) interests. Or, it may relate to activists who oppose elements of the technology or strategy (Negro, 2007; Walz et al., 2016).

Legitimacy also includes the development of policies, strategies and regulations that support the predominant system approach, technology(ies) and associated products (Bergek et al., 2008; Coenen, 2010; Hellsmark et al., 2016).

Collaborative or resistant action

Within the core group of actors identified (see Table 10 in this chapter), the majority emphasise, and therefore, it could be argued, legitimise, biorefinery technologies that focus on certain products, notably biofuels, hemicellulose sugars, nanocrystalline cellulose and xylitol (Sappi, 2017, 2018b; Sithole, 2017; Stafford et al., 2019; Prof. Sithole, Interview 26 & 27, August 9, 2017, August 1, 2018; Dr Sefara, Interview 19, September 3, 2018; Prof. Görgens, Interview

29, September 8, 2018; A Baldo, Interview 9, October 15, 2018; T Bole-Rentel, Interview 33, August 31, 2018). While there appears to be some form of cohesion or legitimacy of emphasis on these priority products, there also appears to be some resistance or competition within the network. This is mainly around who works on what and with whom. This is illustrated in the following leverage professional quotes:

> "The CSIR has put much emphasis on its relationship with Merensky and a couple of other players in the sector, which then puts them in direct competition with the things Sappi are doing. … this means Sappi will not participate in those projects. The same with some technologies that I'm busy with. Some of them overlap with what the CSIR is doing. Some are complementary. If he's [Bruce] got a facility with certain equipment that I need for a project, then I will consider him as a service provider. I certainly don't see that facility as being the centre of biorefinery activity in South Africa. It has a lot to do with the financial model and how CSIR operates also. Everybody knows they're extremely expensive." (Prof. Görgens, Interview 29, September 8, 2018)

> "We don't want centres to compete with us because it's areas where they are working on that are like the areas we are working on. So, we avoid them … It's a fine balance, because when using taxpayers' money, I believe it becomes difficult to manage." (Dr Sefara, Interview 19, September 3, 2018)

It could be suggested that this recognition of competition is due to the scale of the network, and South Africa's limited production capacity (Sithole, 2010, 2017). Consequently, the market is highly competitive, and those investing in or investigating biorefinery technologies wish to protect their potential market share.

Another potential form of resistance is the work being undertaken by WWF-SA's *Waste to Wing* aviation biofuel project. The project's agenda is to promote the uptake of aviation biofuels produced from non-food crop biomass (A Baldo, Interview 9, October 15, 2018; T Bole-Rentel, Interview 33, August 31, 2018; WWF-SA, 2019). In doing so, the project's direct network of project partners, in the main, sit outside the core biorefinery innovation network. A Williams (Interview 23, September 12, 2018) of Citius Energy suggested that this disconnect might be due to some form of resistance to the project. This could be the result of it being seen as a duplication of efforts. He noted, "WWF's *Waste to Wing* work has been done in Colorado on jet fuel, and studies have been done at UCT [the University of Cape Town] on the logistics of sending biomass to Secunda, yet WWF continue to do their scoping study and looking at volumes."

From a more purely defined form of resistance, the SDCEA, in their role as environmental and social activists, would be recognised by industry as outsiders. The irony is that biorefinery technologies and products are eco-innovations that provide an opportunity for the forestry-products sector to mitigate its socio-environmental challenges, as highlighted by the likes of the SDCEA. The development of biorefinery policy and innovation should therefore recognise the voice of 'the activist' to elicit synergies between civil society and industry, as opposed to exclusion.

Given that there is little trust between these two groups, much effort would be required to legitimate their inclusion into core activities of the network and innovation process.

Enabling strategy, regulations and evaluative metrics

Drawing on the work of the economist, North (1994), and TIS author, Markard (2018), the elements of this component were identified as culture, norms, laws, rules, regulations, standards and metrics. Freeman and Louçã (2002) suggested these elements require adjustment as revolutionary technologies are introduced. Adjustments would influence policy, investments, research, and activity focus.

Review of leverage professional interviews and policy documentation suggests there are no coherent norms, laws, rules, regulations, standards or metrics specific to the South African biorefinery innovation system. However, some policies and strategies are aligned. They indirectly encompass and could be adapted to recognise forestry-product and alien vegetation residue and biomass more specifically. Such as:

1. *Green economy and waste policies and strategies*: The waste research, development and innovation (RDI) roadmap for South Africa (SA Department of Science and Technology, 2013; SA Department of Trade and Industry, 2014); Operation Phakisa chemicals and waste economy (SA Department of Performance, Monitoring and Evaluation & Operation Phakisa, 2018); the national waste management strategy (SA Department of Environmental Affairs, 2011; SA Government, 2009; 2014a); and the green economy accord (SA Department of Economic Development, 2011).
2. *Innovation policies and strategies*: *The draft white paper on science, technology and innovation* (SA Department of Science and Technology, 2018c).

3. *Biorefinery-relevant policies and strategies*: The national biotechnology strategy (SA Department of Science and Technology, 2001), *Biofuels industrial strategy of the Republic of South Africa* (SA Department of Minerals and Energy, 2007), *Draft position paper on the South African biofuels regulatory framework* (SA Department of Energy, 2014), and the *Bioeconomy strategy* (SA Department of Science and Technology, 2013a).
4. *Bioeconomy strategy*: Developed off the back of research funded by the DST to assess the feasibility and status of the biomaterials industry in South Africa (Van Rijswijk & Radford, 2016). This research provided an evidence base to inform South Africa's bioeconomy strategy (Dr Rashamuse, Interview 7, September 5, 2018), which includes the forestry-products sector.

These policies and strategies are key drivers for the sector. They enabled it to realise the *National development plan* (National Planning Commission, 2011) and business-led good governance initiatives, such as the Institute of Director's *King IV* (Integrated Reporting Committee [IRC], 2017). The latter is a mandatory set of codes for companies listed on the JSE (including Sappi, Mondi and York Timbers).

While no regulations or legislation are forestry-products- or biorefinery-specific, the *National Environmental Management Act, 1999 (Act 107 of 1999)* (SA Government, 1999) and *Waste Amendment Act* (SA Government, 2014) do apply. Adherence to this legislation would ensure that waste generated at sawmills, from timber products and from pulp and paper operations are dealt with responsibly, or that solutions are sought to prevent waste entering the natural environment.

While the above mechanisms may be in place, Mersham and Skinner (2016) argued that much of the South African response is weak. It is only effective when government legislation is brought into effect to drive social or environmental change. This perspective was substantiated by Borzel and Hamann (2013) in their report on *Business and climate change governance: South Africa in comparative perspective.* They noted that, while the country's environmental legislative framework was relatively well developed, the capacity to implement it was weak.

With reference to metrics, indicators have been generated for the evaluation of science, technology and innovation in R&D and innovation surveys (Kraemer-Mbula & Sehlapelo, 2016). These tend to focus on, for example, gross domestic expenditure on R&D and number of R&D personnel. They also focus on the rate and type of innovation, number of innovation activities and expenditure, and financial support for innovation (Manzini, 2015).

While these surveys could provide an indication of biorefinery innovation activity, they are not regularly undertaken. In addition, it is worth noting that the most recent innovation survey does not mention any biorefinery innovations (HSRC, 2012). Kraemer-Mbula and Sehlapelo (2016) questioned the suitability and limitations of these surveys. For example, for not distinguishing regionality; capturing networks and linkages that create an innovation system; and focusing on inputs rather than outputs and the impact of R&D. They also suggested the surveys illustrated a poor understanding of South Africa's innovation sector, such as a weak recognition of other statistics such as skills, employment, entrepreneurship, race and gender.

Metrics and indicators are currently inadequate for assessing biorefinery innovation activities in the country. It is unlikely this situation will improve, either through improvements in national collection and analysis, or proactively incorporated into monitoring and evaluation practices. In addition, Manzini (2015) suggested there should be a shift from supply-measuring metrics to those that measure demand, for example, knowledge outputs such as licensing of patents and entrepreneurial activity.

7.2.6 Resource mobilisation

Within TIS literature, the resource mobilisation function covers financial and human resources required and available to enable and nurture the system (Bergek et al., 2008; Coenen, 2010; Hekkert et al., 2007; Uriona & Vaz, 2017). Resource allocation is deemed a prerequisite for understanding whether a TIS has the ability to mobilise human competencies (Bergek et al., 2008; Hekkert & Negro, 2009) and financial resources (Bergek et al., 2015; Hekkert et al., 2007; Negro, 2007; Uriona & Vaz, 2017).

Financial mobilisation

Three main streams of financial mobilisation are witnessed in the South African forestry-products biorefinery innovation system: (a) local private investment, for example, Sappi's investment in biorefinery technologies (Sappi, 2016, 2017, 2018b); (b) the government's funding of biorefinery R&D, such as the CSIR's Biorefinery Industry Development Facility (CSIR, 2017a; Sithole, 2010; SA Government, 2018a); and (c) foreign investment, such as the

European Union’s funding of the *Waste to Wing* project through Switch Africa Green (Fetola Foundation, 2019a).

Aside from Sappi and Borregaard’s significant investments, most funding prioritised for biorefineries in the forestry-products sector comes from government. Suurs (2006) suggested that this is reflective of a TIS in its formative stage, a phase in which financial mobilisation generally begins with government and university programmes. As the TIS evolves, private investment increases. The role of the state in funding innovation is contested (Westlake, 2014). Mazzucato’s (2014), in her work *The entrepreneurial state* suggested that government intervention in innovation is problematic. She argued that government takes most of the risks before industry reaps the benefits, with little acknowledgement for doing so. Equally, government should back new innovation, and industry should also invest (Westlake, 2014), particularly in a country such as South Africa, where government funds are stretched.

The leverage professionals also contested who should “foot the innovation bill”. However, it is noticeable that those situated in academia and industry tend to suggest that government should play more of a role in leveraging funding. Government leverage professionals, on the other hand, suggested otherwise, as illustrated below.

Academia and industry comment:

> “In Scandinavia there are many reasons why they are focused on biorefineries. They’ve had to adapt their market as the forestry-products sector began to decline. But they are a much bigger economy, with perhaps a lot more government attention as well. So, it’s more state funding and maybe a more mature industry view.” (Dr Morris, Interview 32, August 2, 2018)

> “[I]n my view, even though the government has recognised this [biorefineries], and has put in place instruments, organisations like the Technology Innovation Agency is an instrument that could be funding this.” (Dr Maseko, Interview 38, September 20, 2018)

> "There is frustration with government being able to support investment in something that is a bit of a game changer. You need funding from the IDC or government." (F Hansen[76], Interview 11, September 4, 2018)

Government comment:

> G Barnes' mandate at the DEA is to "try and find ways to leverage corporate funding to help boost the deficit between what is needed to clear invasive alien plants and what is currently spent by the Working for Water Programme." (Interview 1, October 8, 2018)
>
> In response to the question, "Who do you think should pay for research? Is it government or private?" T Nyanzunda-Kadzombe[77] of the DTI very matter-of-factly stated, "No, private: Government is paying enough already. It's a private fee but maybe they think they're creating their own competition." (Interview 6, September 25, 2018)

A reliance on government funding can be problematic. It is associated with bureaucracy (Jenkin, 2018; Jenkin & Mudombi, 2018; S Kalan, Interview 3, September 5, 2018) and inhibiting time-lags between securing and receiving funds (C Smit, Interview 8, September 4, 2018; Theron, 2018). In addition, the short-term or *quick win* nature of funding does not allow for investment in long-term programmes to shift the system radically (S Kalan, Interview 3, September 5, 2018; J Lyons, Interview 37, October 19, 2018; Dr Trotter, Interview 28, August 1, 2018). These challenges are exacerbated by industry's *wait-and-see attitude* (Prof. Godfrey, Interview 25, October 19, 2018; Prof. Sithole, Interview 27, August 1, 2018), with K Ross (Interview 8, September 4, 2018) of SAFCOL suggesting that private investment will come when there are signs of demand.

Considering the two indicators for assessing a TIS' mobilisation of finances (rising volume of capital and increasing volume of seed and venture capital [Bergek et al., 2008]), the South African forestry-products biorefinery innovation system is short of the mark. Yes, there was increasing investment provided via government, but much of the private investment is

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[76] Frans Hansen is a technical and project manager at Kimberly-Clark's plant in Springs, Gauteng. His role involves project management, process engineering support, packaging, cost transformation and product involvement. He oversees post-graduates, funded through PAMSA, undertaking their studies at Kimberly-Clark.

[77] Tafadzwa Nyanzunda-Kadzombe is the Director of Resource-Based Industries at the DTI. Her role covers forestry-based industries and aims to foster relationships between the DTI and industry to enable South Africa to compete globally, and business sectors to contribute to the local economy.

dominated by Sappi and Borregaard's investment in Sappi's biorefinery operations, thereby demonstrating little rise in additional private investment.

This suggests there is no cohesive national financial strategy, which can be attributed to the disparate market formation, lack of funds and "loose" TIS network. However, with the implementation of the DST's bioeconomy strategy and research platforms, and financial support to the CSIR, a more considered and strategic financial strategy could be likely; that is, if industry is willing to cooperate and collaborate.

Human resource mobilisation

While financial mobilisation is more explicitly referenced in TIS literature, human resource mobilisation is less so. It is sometimes briefly described as the ability of the TIS to attract skilled people to develop scientific and technological knowledge in the system (Hekkert & Negro, 2009; Hekkert et al., 2011). This tends to be the focus in strict TIS studies.

Another component of human resource mobilisation for consideration is the ability to access human competency within the system or the building of the ability (Lundvall et al., 2002). Given the focus of this study on knowledge generation and exchange, the human resource mobilisation element is of importance. The resource mobilisation function of the system is covered in detail in Chapter 8.

7.3 Maturity-level of the biorefinery innovation system

The structural and functions analysis of the South African forestry-products biorefinery innovation system undertaken above provides the basis for assessing the maturity of the system. It is acknowledged that the emergence of technological innovation is a particularly complex, non-linear and iterative process (Edquist, 2005b; Hellsmark et al., 2016; Lundvall et al., 2002; Negro, 2007). R&D and new technologies and products emerge simultaneously, and are dependent on the nature of interactions between "science, technology, learning, production, policy and demand" (Negro, 2007, p. 25). Accordingly, Edquist (2005) suggested that organisations never innovate in seclusion. Even Sappi and Mondi, who are often cited as innovating independently, do collaborate with others when non-competitive situations exist. This is the case when they collaborate on PAMSA initiatives (M Nash, Interview 15, September 6, 2018).

Drawing on Markard's (2018) description of TIS life cycle phasing[78], it can be deduced that the South African forestry-products biorefinery innovation system falls between the formative and growth phases. When asked their views on how advanced South Africa's biorefinery innovation system is, leverage professionals' responses varied. Some suggested the work being done is at the frontier of innovation (Dr Maseko, Interview 38, September 20, 2018) but the majority felt South Africa lagged behind its counterparts in North America, Scandinavia and Brazil, suggesting South Africa "is very far behind" (Dr de Graaf, Interview 10, September 6, 2018; Prof. Godfrey, Interview 25, October 19, 2018; H Nuwarinda[79], Interview 5, October 16, 2018), with I Kerr (Interview 31, August 8, 2018).

While South Africa might be considered laggards, most recognised there is significant biorefinery potential (Mkhize et al., n.d.; Stafford et al., 2019; Prof. Görgens, Interview 29, September 8, 2018; H Nuwarinda, Interview 5, October 16, 2018; P Saayman, Interview 18, August 7, 2018, Prof. Sithole, Interview 27, August 1, 2018).

In terms of the size and sector-base, the innovation system has a small number of actors (in relation to its potential). It has relatively low entry rates and focuses on R&D (Sappi and LignoTech excluded). Currently, aside from Sappi, there is little commercial growth, yet as indicated above, much potential. Another determining variable is the high degree of vertical integration. This is because many timber and pulp and paper companies are involved in the full value chain. According to Markard (2018), this suggests that the TIS is in its formative stage, in comparison to a growth phase, which is characterised by "moderate sales which grow rapidly, [a] medium to large number of actors in different roles, specific associations and intermediaries emerge, high entry rates, strong competition and struggles over standards" (Markard, 2018, p. 18).

With regard to institutional structure and networks, the innovation system also shows signs of being in the formative stage, as there is little formal structure of the network or system and, as indicated previously, much activity is at the intra-network level. An element for consideration in this description is whether value chains exist. A formative TIS would have no value chains.

[78] Size and sector base; institutional structure and networks; technology performance and variation; and context and TIS-context relationship (Markard, 2018).

[79] Henry Nuwarinda is a project manager at the National Cleaner Production Centre South Africa (NCPC-SA), which is funded by the DTI to promote the implementation of resource efficiency and cleaner production in industry.

This is not the case in South Africa, which has some good examples of industrial symbiosis value chains, such as Sappi's collaboration with Borregaard to establish a LignoTech plant to extract lignin from their effluent stream to produce biochemicals (Administrator, 2019). While a couple of examples exist, better advantage could be taken of the opportunities along the value chain. Examples are the improved use of post-harvest in-field residue (Dr Längin, Interview 14, August 6, 2018), and sawdust and wood off-cuts generated during sawmilling (Jenkin & Mudombi, 2018; P Saayman, Interview 18, August 7, 2018; Prof. Sithole, Interview 27, August 1, 2018). Therefore, one could suggest that, while the forestry-products value chain is cohesive, it does not realise the full potential of the biorefinery opportunity.

From the perspective of alien vegetation, the value chain is well understood; however, numerous significant challenges hinder the full realisation of biorefinery potential. This is due to disconnected actors, financial constraints and a national business model that has significant systemic issues (Jenkin & Mudombi, 2018; Ward et al., 2017).

As noted earlier, the forestry-products and alien vegetation actors seldom collaborate. If they were to strengthen their ties, the country's biorefinery innovation system could transition to a growth phase as different markets develop and networks become better linked (Markard, 2018).

Technology performance and variation maturity determinants in the system are unclear. Aside from Sappi and LignoTech, much of the biorefinery innovation focus is on R&D, with little evidence of transformation to commercialisation or increased adoption. Performance can therefore be determined as low and vague. Prof. Sithole (personal communication, March 4, 2019) of the CSIR, supported this finding. He suggested there is little information on biorefinery activities associated with the forestry-products sector.

While the R&D in the country tends to focus on a relatively small number of biorefinery products (Prof. Görgens, Interview 29, September 8, 2018), more technology and product variety is required. This should be a prerequisite to TIS performance. It enables the dominance of more fit-for-purpose biorefinery technologies or products to emerge., and would indicate a TIS in its growth phase (Markard, 2018).

From the perspective of the TIS-context relationship, the South African forestry-products biorefinery innovation system also has characteristics associated with a TIS in its growth phase. This is demonstrated by a system in which collaboration becomes more formalised, and conflicts begin to arise, as well as an element of co-dependence (Markard, 2018). This can be seen, while disconnected, in the formation of collaborative networks around the CSIR demonstration laboratory. It was established to provide an open and secure innovation platform for industry and academia to explore and pilot opportunities pre-commercialisation. The open innovation business model associated with the laboratory is beginning to show up potential areas of conflict, such as the development of technologies that could compete with Sappi's activities (Dr Sefara, Interview 19, September 3, 2018) or could reduce support to other academic or civil society programmes.

7.4 Conclusion

Drawing on the analysis undertaken in this chapter and comparing it to an ideal TIS (Chapter 4), it is possible to determine the efficacy and collaborative dynamics of South Africa's forestry-products biorefinery innovation system. While all quadruple helix actor groups are present, the system is dominated by a typical triple helix grouping of industry, academia and government. The strongest ties are between industry and academia, and there is little acknowledged connectivity with civil society. This is predominantly due to a long-standing relationship of secondment and research collaboration between industry and academia. This is explored further in Chapter 9, as many leverage professionals have a close relationship with the universities where they studied.

This leads to the critical factor of a collaborative network, that of trust. Trust is complex. Signs of mistrust were evident throughout the system, particularly between industry and the more activist civil society organisation, SDCEA. Mistrust was also witnessed between Sappi and the CSIR regarding working in the same space. It was felt conflicts of interest could arise from this. Given some of the trust issues raised, mutual beneficiation in the network is debatable. This is because access to knowledge and practice is not as open as it could be. It is possible that trade associations could play more of an intermediary role in this respect, to open the channels of exchange and enhanced collaboration.

From a governance and ownership perspective, no one forum or network for forestry-products biorefinery initiatives exist. As with similar findings identified by Bauer et al. (2018) on the dynamics of biorefinery networks in Sweden, much of the network activity is at the intra-level. In other words, there are smaller and more siloed networks within the broader biorefinery innovation system. In the case of South Africa, these smaller networks tend to be established around research and applied projects, alien vegetation interest, or biorefinery government-funded initiatives.

I argue that, for the network to become more collaborative from a governance perspective, the intra-networks need to be more connected, to enable a more even distribution of funding and capacity, and to improve operational efficacy by reducing duplication. Most significantly, I feel the activities of the traditional forestry-products and alien vegetation value chain actors need to be linked.

A notable issue of the South African TIS is funding, as it has an impact on the efficacy of the system. This affects the ability to move from a system dominated by R&D to increased biorefinery uptake. Most of the funding is currently provided via government channels, which is often short-term and channelled, in the main, through the CSIR. From an industry perspective, most leverage professionals felt government should play a more significant role in catalysing uptake by providing incentives and financial support. This is a contested arena, given the financial instability of the government, high levels of bureaucracy and the short-term nature of funding. Industry and external donor funding, as in the case of *Waste to Wing*, should be enhanced to expedite applied change.

Regarding the level of collaboration, there is little evidence to illustrate equitable inclusion of civil society in the forestry-products biorefinery innovation process. The SDCEA is the most representative of an 'activist' NGO-type, yet it sits outside the core group of actors within the network. As suggested earlier, this is most likely due to issues of trust and the nature of its work to challenge the industry about its environmental impact.

While GreenCape, WWF-SA and TIPS do have projects to catalyse change, there is little evidence of government, industry or academia using their work to inform biorefinery innovation strategy or implementation. However, the fact that there are examples elsewhere in the forestry-products sector of higher levels of collaboration between civil society organisations and industry suggests a more enhanced level of collaboration in the biorefinery innovation system is possible. These examples were identified in water conservation, such as Mondi's collaboration with WWF-SA to conserve wetlands (University of Cambridge, 2017), and alien vegetation harvesting to create rural jobs (SA Department of Public Works et al., 2017; Parliamentary Monitoring Group, 2017). Learning from these initiatives could be drawn on to enhance collaboration in the biorefinery innovation system, particularly in areas of entrepreneurship, market formation, capacity development and the social impact of innovation.

Drawing on the structural dynamics assessment, a more collaborative South African forestry-products biorefinery innovation system should include:

- *government departments* (such as the DST, DTI, DoE and DEFF), and government delivery vehicles (such as the IDC and the National Cleaner Production Centre of South Africa [NCPC-SA])
- *industry* (such as the major forestry-products companies), and those involved in biorefinery and woody biomass byproduct conversion. This includes entrepreneurial activities (including alien vegetation), and industry associations. Members of the latter could benefit from and implement biorefinery initiatives (such as PAMSA, Sawmilling SA and Forestry SA)
- *academia*, such as chemical engineering and forestry departments, and the social and business sciences. This includes research institutions such as the CSIR and ICFR
- *civil society* to aid in the facilitation of biorefinery uptake, unlock jobs, open new markets, challenge the *status quo*, and present scenarios for a more sustainable future

From the perspective of demonstration and capacity, knowledge and skills relate to the knowledge generation and diffusion component of this study. The establishment of the CSIR's Biorefinery Industry Development Facility illustrates the recognition that, through demonstration and collaboration, biorefinery opportunities can be realised. The facility is still young, with leverage professionals adopting a questioning perspective. If the facility can overcome some of the issues of competition, cost and limited product focus, it could become a central hub for the country's biorefinery innovation system. Given the facility's ambition to demonstrate the benefits of biorefineries, learning and capacity become critical factors for transitioning from R&D to increased application. The issues of being "stuck" in R&D, and of requiring additional R&D investment to stimulate innovation, are often reflected in innovation literature (for example, Diaz-Balteiro et al., 2011; Klomp, 2001; O'Connor, 2019). A recommended solution is the enhancement of collective learning through a learning alliance. This was proposed by Lundy et al. (2005, p. 1), who noted that "millions of dollars are spent each year on research and development (R&D) initiatives in an attempt to improve rural livelihoods in the developing world" yet problems still remain. While their research was set within an agricultural context, the concept of a "learning alliance" to shift from R&D to improved praxis aligns with the notion of a TIS and its associated knowledge network. This is a key element of this study and covered in-depth in the following chapter.

Chapter 8: Dynamics of the South African forestry-products biorefinery innovation system's knowledge network

The premise for this chapter is that an innovation system hinges on the interaction of actors and individuals who, through collaboration, generate and exchange knowledge (Adamides & Karacapilidis, 2006; Cohen & Levinthal, 1990; Cooke et al., 1998; Cowan, 2004; Edquist, 2005b; European Commission, 2016; Evers, 2014; Kogut & Zander, 1992; Markard & Truffer, 2008; Metcalfe, 2007; Sammarra & Biggiero, 2008; Van Eijck & Romign, 2009; Yli-Renko et al., 2001). This collaboration is a social learning process (Coenen et al., 2017; Grønning & Fosstenløkken, 2015; Lundy et al., 2005). Individuals share and circulate knowledge for the benefit of innovation (Carayannis et al., 2015; Gibbons et al., 1994; Nordqvist & Frishammar, 2018). Their alliance forms the social capital of a system or network (Aral & Van Alstyne, 2011).

The TIS framework recognises knowledge and competency in three of its functions: knowledge development in Function 2, knowledge diffusion through information exchange in Function 3, and as human resource mobilisation in Function 6 (Bergek et al., 2008; Bergek et al., 2010; Coenen, 2010; Hekkert & Negro, 2009; Markard, 2018; Negro, 2007; Uriona & Vaz, 2017; Walz et al., 2016). However, for the purposes of this study, these function indicators are limiting. They predominantly explore knowledge generation, diffusion and human capability through, for example, calculating the number of R&D projects undertaken, patents granted, and conferences held to indicate the level of knowledge-related activity (knowledge diffusion).

These indicators do not constitute an adequate tool for assessing the *dynamics* of the knowledge network associated with the South African forestry-products biorefinery innovation system. Given this, I drew on two literature sources to undertake an assessment of the knowledge network dynamics, including the network ties, shared languages, narratives and relational elements. These sources were Nahapiet and Ghoshal's (1998) dimensions of social capital, and the work of Bonfim et al. (2018), who adopted Nahapiet and Ghoshal's framework in the context of innovation and technological development.

The purpose of this chapter is firstly, to understand the dynamics of the knowledge network associated with South Africa's forestry-products biorefinery innovation system; and secondly, to assess how knowledge is generated and diffused within the network. Therefore, this chapter will contribute to existing TIS literature in two ways: first, by highlighting the importance of understanding the types of knowledge held within a TIS, moving beyond the valuing of techno-economic knowledge and capabilities for innovation; and second, by advancing current TIS discourse to more explicitly incorporate and recognise the importance of actor and leverage professional connections. This includes the role they play in expediating or hindering innovation uptake.

The chapter presents the findings in four overarching themes: first, the characteristics of the South African forestry-products biorefinery knowledge network in relation to its structural, relational and cognitive dimensions; second, how knowledge is generated and acquired and what type of knowledge is generated and acquired; thirdly, the dynamics of the knowledge transfer interface and mechanisms of exchange; and finally, the knowledge competencies and capabilities held within the network. This provides a platform for exploring the role leverage professionals play within the knowledge network as agents of change, which follows this chapter.

8.1 Structural, relational and cognitive dimensions of the knowledge network

As indicated previously, the analysis of the dimensions of the South African forestry-products biorefinery innovation system's associated knowledge network drew on a social capital analytical framework. This framework was set out by Nahapiet and Ghoshal (1998) in the context of innovation and technology development (Bonfim et al., 2018). These dimensions provide an explanation of what Culpepper (1996, p. 7) referred to as the "software of co-operative capacity" (compared to the formal organisational structure [hardware]).

In essence, the fluidity and informality of the network is defined structurally, relationally and cognitively. This is to develop a sense of how it is connected, who is connected to whom, and whether gaps exist. These gaps have been referred to as *black holes* by Li et al. (2018, p. 4) or *isolated nodes* by Sammarra and Biggiero (2008, p. 811). Using Sammarra and Biggiero's (2008) measurement method to assess inter-firm knowledge flows in innovation networks, a platform was built for investigating knowledge transfer in the network.

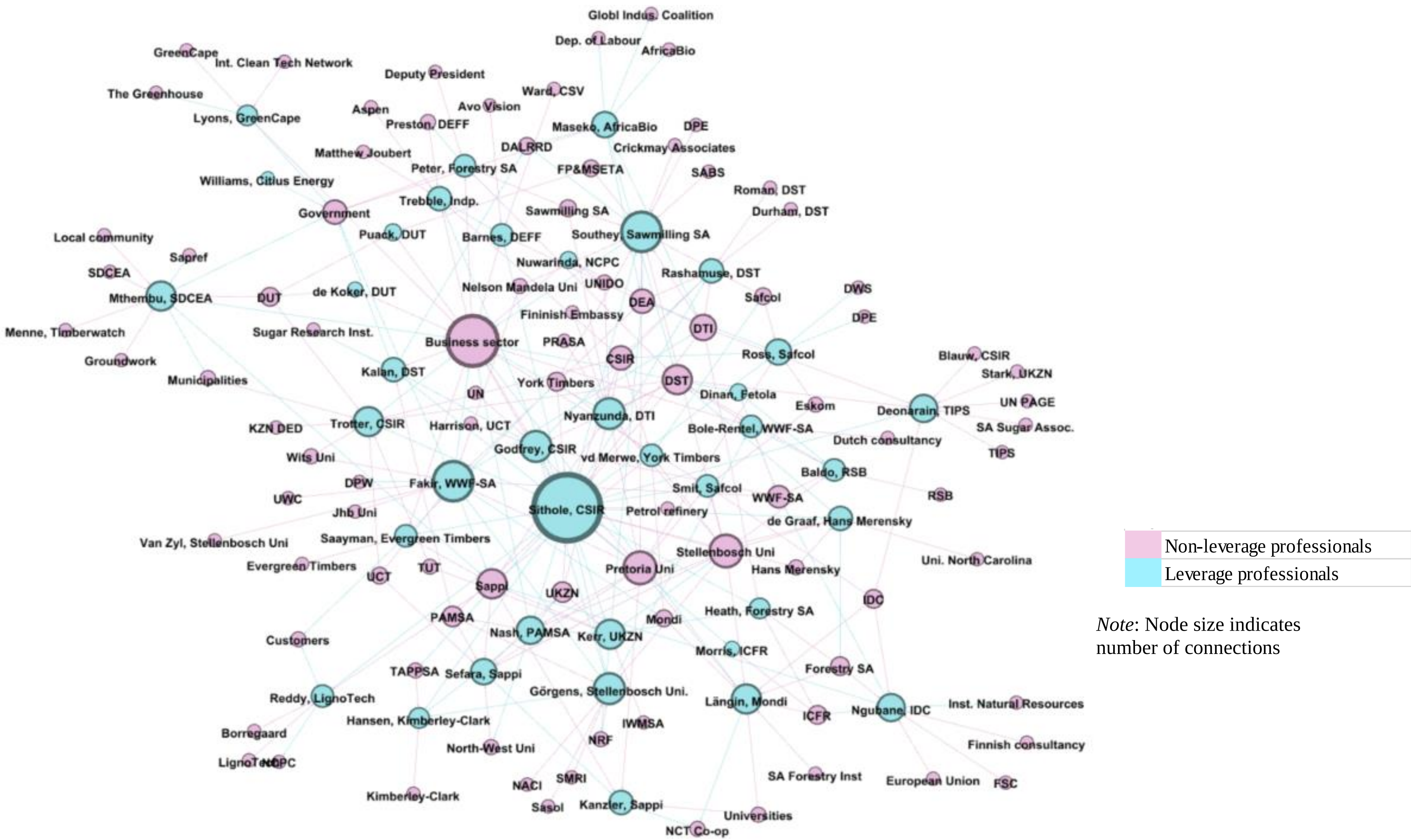
8.1.1 Structural dimension

The structural dimension covers the extent of the network's social capital, channels through which interaction is facilitated, and knowledge is generated and exchanged (Nahapiet & Ghoshal, 1998; Sułkowski, 2017; Van Reijsen, 2014). This dimension includes the strength and cohesiveness of the ties between individuals (Bonfim et al., 2018; Nahapiet & Ghoshal, 1998), as well as the diversity of individuals in the knowledge network (Nahapiet & Ghoshal, 1998).

As indicated in the previous chapter, South Africa's forestry-products biorefinery innovation system is not formalised, unified or recognised as a singular system. It is only through this study that the linkages and the structural dimensions of the knowledge network have been revealed for the first time.

While the previous chapter mapped the actor relationships (see Figure 6), this section maps the linkages between the leverage professionals (see Figure 7). It also investigates the centrality of those who generate and diffuse the most knowledge (i.e., those who have the most knowledge-related connections [Grandjean, 2015]). The map is based on how leverage professionals responded to the question of whom they engaged with to exchange knowledge.

Figure 7: Centrality of interviewed leverage professionals within the South African forestry-products biorefinery knowledge network



Note: Node size indicates number of connections

As noted by Van Reijsen (2014), the value of this type of map is that it illustrates the linkages between the individuals who exchange knowledge. It is from this that the knowledge flows and knowledge disseminators can be identified.

The network illustrates two node types: (a) the leverage professionals interviewed as key individuals in the South African forestry-products biorefinery innovation system (pink); and (b) individuals or organisations the leverage professionals cited with regard to generating or diffusing knowledge. While the map does not illustrate the full network,[80] it is indicative of the potential scale of the biorefinery knowledge network. The 39 leverage professionals interviewed collectively named over 90 individuals or organisations they engaged with to generate or diffuse knowledge.

Several focal leverage professionals stand out. They are identifiable in Figure 7 by node size – the larger the node, the more significant the degree of centrality and the number of connections (Grandjean, 2015).

Leverage professionals with the greatest level of connectivity (based on their stated connections) are presented in Table 10, which also indicates the direction of knowledge flow. *In* refers to knowledge received and *out* to knowledge diffused or generated by a leverage professional. *Mutual* refers to instances when both individuals cited each other as receiving and diffusing knowledge.

[80] The network illustrated was developed using information from those interviewed only.

Table 10: Top 20 leverage professionals with the greatest level of connectivity, by knowledge transfer type[81]

Leverage professional		Organisation	Number of interactions			
			In	Out	Mutual	Total
1	Prof. Bruce Sithole	CSIR	6	**14**	9	**31**
2	Saliem Fakir	WWF-SA	5	**6**	5	**16**
3	Roy Southey	Sawmilling SA	**6**	3	**6**	**15**
4	Prof. Johann Görgens	Stellenbosch University	**4**	3	**4**	**11**
5	Tafadzwa Nyanzunda-Kadzombe	DTI	2		**9**	**11**
6	Bongani Mthembu	SDCEA	4	**5**	1	**10**
7	Dr Dirk Längin	Mondi SA	**4**	3	3	**10**
8	Dr Douglas Trotter	CSIR	2	**1**	7	**10**
9	Iain Kerr	UKZN	**5**			**10**
10	Prof. Linda Godfrey	CSIR	**6**	2	2	**10**
11	Bhavna Deonarain	TIPS	**5**		4	**9**
12	Mike Nash	PAMSA	1	3	**5**	**9**
13	Steven Ngubane	IDC	1	4	**4**	**9**
14	Dr Bongani Maseko	AfricaBio	1	**7**		**8**
15	Kira Ross	SAFCOL	**3**	**3**	2	**8**
16	Dr Nelson Sefara	Sappi	**5**	1	3	**8**
17	Grant Trebble	Independent	**5**	1	1	**7**
18	Dr Johan de Graaf	Hans Marensky Holdings	2	2	**3**	**7**
19	Dr Konanani Rashamuse	DST	**7**			**7**
20	Sunita Kalan	DST	**3**	**3**	1	**7**

The centrality of these leverage professionals provides them with the privilege of easily accessible and more diverse knowledge and information (Adeel et al., 2018; Nahapiet & Ghoshal, 1998). It also enables them to determine the flow of information (this is discussed further in this chapter) (Evers, 2014; Markard & Truffer, 2008). Their embeddedness in the network catalyses new opportunities through knowledge exchange (Tsai, 2001) and subsequently motivates the leverage professional to continue to interact and exchange knowledge (Adeel et al., 2018). Therefore, the strength of the ties between the leverage

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[81] *Note 1*: It is important to stress that this table is indicative of knowledge exchange within the network, as it is based on mentions within the leverage professional transcripts, as opposed to a more quantitative exercise in which leverage professionals were asked to map their knowledge network. As such, it can be assumed that this is an underestimate of interactions and knowledge transfer in South Africa's forestry-products biorefinery innovation system.

Note 2: Numbers highlighted in bold indicate the largest number of interactions per leverage professional, by knowledge transfer type.

professionals in the network is important. This demonstrates how connected they are to each other, where gaps exist, or who is most active or utilised in the network.

Referring to Table 10, individuals such as Prof. Sithole of the CSIR and Dr Maseko of AfricaBio display a strong tendency to diffuse knowledge. For Prof. Sithole, this is predominantly because others within the network refer to him for his expertise and insights on biorefinery opportunities within the forestry-products space. For example, B Deonarain (Interview 35, September 7, 2018) of TIPS, stated she had interviewed Prof. Sithole to inform a piece of biorefinery policy research (see Montmasson-Clair, 2019). Dr Morris (Interview 32, August 2, 2018) of ICFR and P Saayman (Interview 18, August 7, 2018) of Evergreen Timbers, noted conversations and site visits with Prof. Sithole to improve their understanding of biorefineries and the potential value-add opportunities these had to offer the forestry sector and sawmilling operations respectively. In the case of Dr Maseko, his job function is to engage with stakeholders to encourage and enable them to adopt bio-related interventions. For example, one of Dr Maseko's roles is to advocate the importance of biotechnology to government (Interview 38, September 20, 2018).

For individuals such as Prof. Godfrey of the CSIR, I Kerr of UKZN, Dr Sefara of Sappi, G Trebble (an independent) and Dr Rashamuse of the DST, their interactions and level of connectedness are more inward-focused. In their interviews, they referred predominantly to engaging with others to access information to inform the work they do. Dr Sefara and G Trebble seek knowledge to leverage their own business agendas to enhance the work they do or wish to become involved in. For Prof. Godfrey, Dr Rashamuse and I Kerr, their need to access knowledge is linked to their work being research-focused, which requires the gathering of information and insights from others to inform their research.

Having mutual connections appears the strongest for T Nyanzunda-Kadzombe of the DTI, Dr Trotter of the CSIR, and M Nash of PAMSA. This becomes understandable when reviewing their job functions, which are to connect and coordinate relationships. T Nyanzunda-Kadzombe engages with industry to support and encourage the uptake of innovation to enhance the national economy. She also uses her network to garner insights to inform innovation policy (Interview 6, September 25, 2018). M Nash oversees PAMSA's Process Research Unit. This requires a significant amount of coordination between academia and the sector to ensure student research is well informed by industry, and fit-for-purpose (Interview 15, September 6, 2018). The same coordination role applies to Dr Trotter. He engages with CSIR colleagues, universities and industry to ensure the programmes he oversees meet market needs, and to secure an income for the organisation (Interview 28, August 1, 2018).

The two individuals most cited by the leverage professionals were Prof. Sithole of the CSIR and Prof. Görgens of Stellenbosch University. The main reasons given were their expertise in and knowledge of biorefineries in a South African context. They both have extensive experience in biorefinery research and have become what Pisano (2015, para. 7) referred to as a "repository" of accumulated expertise within the network.

The issue of over-reliance on these two individuals by the system is potentially problematic because much of their experience is conceptual and research-focused, with little applied expertise. It could constrain the broader absorptive capacity (Jensen et al., 2004; Lundvall et al., 2002) of the TIS because the skills and expertise in the system are not evenly distributed or diverse. This could lead to a bias or a lack of critique of the information they exchange, and there are implications if one or both retire or leave the system. Who would replace them? The latter is a concern raised by Prof. Sithole (Interview 27, August 1, 2018).

The knowledge network also comprises over 90 other individuals and organisations identified by the leverage professionals. These other entities were identified as sources of knowledge, or as those to whom they have transferred knowledge (see blue nodes in Figure 7). However, it can be assumed that organisations or clusters of actors represent more than one individual. These clusters or organisations are likely to be indirectly linked to the system. For example, the reference by P Saayman of Evergreen Timbers to "customers" relates to his current sawmill customers who purchase the mill's timber products (Interview 18, August 7, 2018). While not linked to his biorefinery intentions, they could be linked in the future, or become associated with his actions.

Table 11 provides an indicative list of the top 15 organisations cited by the leverage professionals in relation to knowledge exchange. It indicates the receipt of knowledge (in), diffusion (out), or both (mutual exchange).

Table 11: Top 15 organisations cited by leverage professionals for knowledge exchange, by interaction type

Other named clusters and organisations		Number of interactions			
		In	Out	Mutual	Total
1	Business sector (overarching category)	9	1	**11**	**21**
2	Pretoria University		**10**	2	**12**
3	Stellenbosch University	1	**8**	3	**12**
4	DST	2	3	**5**	**10**
5	Sappi	3	2	**5**	**10**
6	DTI	2	2	**4**	**8**
7	CSIR	1	**3**	**3**	**7**
8	DEA	**4**	2	1	**7**
9	Government (overarching category)	**5**	1	1	**7**
10	WWF-SA	**2**	**2**	**2**	**6**
11	PAMSA		2	**3**	**5**
12	University of KwaZulu-Natal	1	**2**	**2**	**5**
13	Durban University of Technology	1		**3**	**4**
14	Forestry SA	1	**2**	1	**4**
15	ICFR	1	**3**	1	**4**

Table 11 clearly illustrates that (aside from Sappi) the TIS' efforts are focused on R&D. Nearly all those reflected in the top 15 either fund biorefinery R&D or provide research support. Pretoria and Stellenbosch Universities were regularly cited by leverage professionals as central to knowledge generation and diffusion. This appears to be for two main reasons:

1. *Expertise* – Pretoria University is cited for its forestry science, and genetics and control of pests and diseases knowledge and research. Stellenbosch University is mentioned with respect to its forestry, agriculture and chemical engineering departments.
2. *Alumni connection* – of the 39 leverage professionals interviewed, a third had studied at either Pretoria or Stellenbosch University. It is therefore evident that the benefit of the relationship with their *alma mater* continued post-study. This is most likely due to their familiarity with the institution's *modus operandi* and knowing the individuals in the departments where they studied. This in turn creates a level of trust. This aspect is explored further in Section 8.3 in this chapter.

Markard (2018) suggested these strong ties with academia and research institutions are an indicator of a TIS in its formative and growth phases, both of which he described as having an R&D focus indicator. This R&D focus also explains the strong links to and citings of the DST, DTI and DEA. The DST and DTI are mandated to initiate and support enterprise development. The DST has a specific focus on bioeconomy and biorefineries. It has established a biorefinery research consortium and platform, published biotechnology and bioeconomy strategies for South Africa, and funded the CSIR's Biorefinery Industry Development Facility.

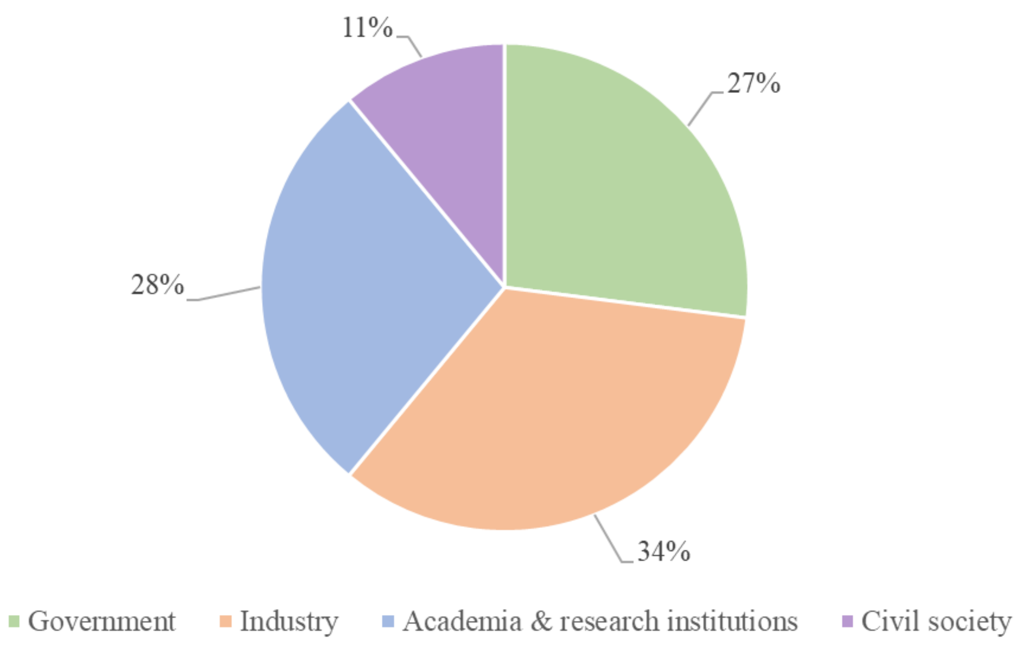
The DEA is most often referenced in terms of its mandate to regulate and deal with waste. This includes job creation, the eradication of alien vegetation and adding value to harvested biomass. Biorefinery products are considered an option for all these activities (see SA Department of Environmental Affairs, 2019a). As such, many of the national government department citings in interviews were about developing policy, receipt of funding, or advocacy. Advocacy was a key reason cited by civil society leverage professionals within GreenCape, WWF-SA and TIPS; and forestry sector trade associations who advocate on behalf of their stakeholders.

In more than half of their responses, the *business sector* was regularly cited by the leverage professionals as the cluster they engaged with most often. However, mention of the business sector highlights the disconnect between R&D and the implementation of biorefinery activities in the forestry-products sector. Few businesses are engaged in biorefinery practice, with most adopting a *wait-and-see* approach. As indicated in Chapter 6, the broader South African biorefinery innovation system exhibits the characteristics of a TIS in its formative phase, of which a key indicator is the focus on R&D and not commercial activity. The mention of the business sector by leverage professionals suggests the sector is perceived as critical for biorefinery uptake. The DST funded the CSIR's biorefinery facility as a site of demonstration and piloting for industry in the hope that the R&D carried out at the facility would catalyse uptake (S Ngubane, Interview 4, August 2, 2018). In their paper on the role of demonstration plants in technological development, Frishammar et al. (2015) confirmed the value of demonstration facilities. These authors suggested demonstration facilities play an integral role in bridging the gap between knowledge generation and technological advancements, industrial application and commercialisation. They, along with Smith and Raven (2012), made a significant point which relates to the DST's funding of the facility (CSIR, 2017a; SA Government, 2018a), which was to demonstrate and provide a protected space for niche markets (Geels, 2002) to be developed. In addition, in this space, knowledge sharing can encourage private and government funding.

Leverage professionals also cited the organisations they were employed by as sources of knowledge. This recognition of intra-firm knowledge exchange highlights factors of trust, knowing each other and knowledge generation practice, notably tacit knowledge (learning-by-doing). The first two factors continue to appear throughout this study as critical dimensions for knowledge generation and exchange in a knowledge network. These are discussed further below. Intra-firm tacit learning in this context is reflected in Grønning and Fosstenløkken's (2015, p. 5) recognition of learning-by-combining and learning-by-interacting. Mechanisms associated with intra-firm knowledge exchange include working in "teams, discussions and meetings, training and mentoring" (Usman et al., 2019, p. 4). These were all mentioned by the leverage professionals and are discussed further in this chapter.

Figure 8 illustrates the split of actor groups most cited by leverage professions regarding knowledge exchange. Most notable are references to industry (including trade associations) (34%), academia and research institutions (28%), and government (27%). These exchange relationships reiterate the focus on R&D in the biorefinery innovation system. They also reiterate the dominance of a triple-helix model of actors involved in the innovation process.

Figure 8: Knowledge exchange actor groups cited by leverage professionals[82]



[82] Derived by the author.

In conclusion, Figure 7 illustrates structurally that the South African forestry-products biorefinery knowledge network is complex. Not everyone is connected. There are clusters of individuals who emerge as central nodes of knowledge generation (*go-to people*) or diffusion. However, there is a bias towards R&D. Nevertheless, there is a desire within the system to engage with the business sector in the hope that it will grasp the codified research and demonstration learnings and translate these into commercially viable, and improved operations.

8.1.2 Relational dimension

While the structural dimension covered the dynamics of the linkages in the knowledge network, the relational dimension explores common language(s), shared values and levels of trust (Bonfim et al., 2018; Moos et al., 2012; Nahapiet & Ghoshal, 1998; Van Reijsen, 2014). These elements, or the lack thereof, can either enable or inhibit effective and efficient knowledge exchange within a social network (Nahapiet & Ghoshal, 1998).

Shared value, knowing of each other and common language

The element of shared value and common language can be interpreted as the value of existing knowledge, experience and relationships, something I wish to propose as *knowing of each other*. In the forestry-products sector, having a history of studying or working together previously clearly has resonance, as it provides a common and shared value.

All the academics interviewed have a strong relationship with industry, particularly through secondments from industry to academia. I Kerr of UKZN and Dr Pauck of DUT are good examples of this. Dr Pauck was seconded from Mondi (Interview 24, August 8, 2017) and I Kerr from PAMSA (Interview 30, August 7, 2017; August 8, 2018). Luna and Velasco (2010, p. 318) referred to secondees as *translators*, suggesting they have worked in both industry and academia. This provides them with the knowledge and experience of understanding the culture and procedures of both industry and academia. Accordingly, they can span the boundaries or act as brokers between different actor groups (see Chapter 6, Section 6.2.1). They also argued that these individuals possess high amounts of tacit knowledge. As such, they “command all types of knowledge: know-who, know-what, know-how and know-why” (Luna & Velasco, 2010, p. 312).

Industry experience is beneficial, not only to the academic institutions in which the secondees are situated but also to industry. This is because secondees can be called on by industry to provide onsite training, for example (as cited by I Kerr, Interview 30, August 7, 2017). Secondment also means that industry-sourced academics can influence and guide course and programme curricula and areas of research. This is to ensure academic study is business relevant, as explained by Dr Pauck (Interview 24, August 8, 2017):

> "All of the lecturers were seconded out of the industry. Having been in the industry and worked there, you kind of know what was needed … we're in touch with what's happening [in industry]."

However, secondments from the sector are facing an uncertain future due to reduced funding as the industry's budgets become "tighter" (Dr Pauck, Interview 24, August 8, 2017). In the same interview, Dr Pauck's colleague, Prof. de Koker,[83] raised concerns about this shift in practice. He noted that, while he was also seconded from industry, his position at DUT had changed from temporary employment to permanent. This he felt could limit his desire to have the flexibility to "go back into industry for a month" and return to academia with new insights (Prof. de Koker, Interview 24, August 8, 2017). Such a shift could jeopardise the important role secondments have in ensuring academics are kept up to date with industry practice and areas of focus.

The importance of trust in knowledge exchange

In his work on social capital, trust and intercultural transactions, Sułkowski (2017, p. 155) warned that "not all networks or relationships are good building blocks for social capital". He suggested that "only those where there is a relatively high level of trust, are suitable" (ibid., p. 155). Trust, or the lack thereof, is therefore considered a critical element in the implementation of an effective innovation system. Those operating within the system's associated knowledge network need to have mutual respect and to trust the integrity of those they collaborate with (Luna & Velasco, 2010). This is to create a conducive environment for knowledge transfer, for the development of innovative solutions and to reap mutual benefits.

Within the South African forestry-products biorefinery knowledge network, mistrust was identified between academia, industry and civil society, and between business and government.

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[83] Prof. Theo de Koker, at the time of interview, was in the process of stepping into Dr Pauck's position as Head of Programme for Pulp and Paper Technology, Department of Chemical Engineering, DUT. His academic and research interests are in process integration and biorefinery innovation.

For example, the relationship between the pulp and paper sector and SDCEA could be labelled as *hostile* and lacking in trust.

The following quote from B Mthembu (Interview 39, August 31, 2017), of the SDCEA, illustrates this point. He explained his reasoning as to why the government is unlikely to follow up and enforce the law, even if evidence of industry pollution is provided by the SDCEA or surrounding community:

> "If an ordinary community member, be it in Merebank or Wentworth or Isipingo, were to challenge any industry, I don't think they will win. It would be a futile exercise, because these industries can lobby government … their shareholders are big top guns … that's why when we as an environmental justice organisation and community try to expose and bring industry to book to government officials that have the authority to penalise them, or prosecute them, unfortunately the big guys, the decision-makers [in government] also have their fingers in the pie."

This finding is not unusual, with Dunkley and Franklin (2017, p. 1) suggesting that having a *green identity* at a local level can have "a negative impact on wider community engagement within environmental projects" and therefore a relationship of mistrust develops, and is exacerbated through assumption, as witnessed again (see quote below) in my interview with B Mthembu of the SDCEA. He has little faith in the information industry publishes on its environmental initiatives. Within environmental sustainability discourse, this is referred to as *greenwashing*, which means a company makes environmental and social claims that are considered symbolic as opposed to genuine, proven and significantly beneficial (Blome et al., 2017).

> "You know, it's very difficult to work with industry because industry might claim to be a good neighbour, but if you go to those communities and ask them what they really think about these industries being good neighbours in terms of transparency and pollution reduction, they will tell you that it's a myth … if you come to think of it, they [industry] care nothing for the community." (B Mthembu, Interview 39, August 31, 2017)

Both of B Mthembu's examples below illustrate how mistrust can inhibit knowledge transfer and acquisition, especially from the perspective of hindering civil society integration into an innovation system or process. The first is an example of citizen knowledge not being recognised, and the second shows disbelief in the knowledge that is distributed by industry.

An analysis of the language used by the leverage professionals can also expose why collaboration and knowledge exchange are impeded by mistrust and misunderstanding. For example, the language used [italicised] by B Mthembu clearly illustrates the SDCEA's approach to knowledge sharing and their relationship with the pulp and paper industry.

> Example 1:
> "When some detergent was released into the ocean last year and foam could be seen coming from their outlet pipe, the fisher folk informed us. We *challenged* the industry. It made it into the media because we were able to *expose* them with our partners working in that area as well. … the [City's] Department responsible for water pollution came out to take samples. We also took our own samples and sent them to the lab for analysis. Then we called the relevant authorities, and industry as well, to say 'we can see what you are all doing, *you'd better shut and stop whatever you're doing immediately*, because this is affecting marine life as well as the fisher folk.' … they [industry] couldn't deny it, it was obvious because it came from their pipeline. But they were like 'no, it was just a little detergent, half a pint of soap … it's not so harmful to the environment … *don't worry about it'*." (B Mthembu, Interview 39, August 31, 2017)

> Example 2:
> "In the plant in Umkomaas for example, there's a guy there … he's the person *we fight with a lot* if we don't see eye to eye … if there's something wrong then *we definitely put pressure on them*." (B Mthembu, Interview 39, August 31, 2017)

A similar example of emotions or rationality being raised as a challenge to knowledge sharing between civil society and industry was given by Dr Pauck (Interview 24, August 8, 2017) of DUT. When responding to a question as to whether civil society could be incorporated into an innovation process, he drew on personal experience as an example:

> "[R]ecently, this dumpsite has started to emit really bad smells and now the community is up in arms. The community is not a simple rural community; they've got people who know things. One friend, she's got a PhD in oncology but nevertheless she is highly educated, yet she still operated at a very *emotional level*. … with these sorts of things, there just doesn't seem to be any space to sit down and discuss things rationally. The

> *companies are resistant* to that, so *they put up a wall*, and then the community senses that so they *become irrational*. If you try and follow her line of logic, then *you're regarded as a sell-out*. As I say, even educated people fall into these roles."

With reference to the community living next to industry in the South Durban basin, B Mthembu (Interview 39, August 31, 2017) said, "the whole thing just seems to become really *irrational* with the paper industry, and it's like this with the Durban South community."

B Mthembu and Dr Pauck's examples suggest that, while individuals or civil society may hold and share knowledge to solve problems, this appears to be irrelevant when dealing with industry. What overrides this is the value of perception, context, who is trusted, the communication style adopted, and who is assumed to have respected knowledge. It suggests, therefore, that industry and academic institutions hold recognised knowledge and civil society does not. If the academic's role transitions to that of a community member, this knowledge can be dismissed and considered irrational and excluded from the discussion or process. This harks back to the days of enlightenment when a grand narrative or acknowledged objective truth excluded other narratives; the grand narrative was deemed rational and the only accepted knowledge (Burger, 2008). It can be argued that holders of recognised knowledge are able to exert their position within the relationship and, therefore, control the knowledge and its diffusion, resulting in an undemocratic and unequal knowledge network (Arocena, 2018).

Culture and race within the context of trust and knowledge exchange.

While not evidenced in the interviews, it would be remiss of this study to not acknowledge the role played by culture and race; particularly with regard to trust, which therefore has the potential to inhibit knowledge exchange in the network. This is an issue recognised by Bouraoui et al. (2011, p. 73) in their study on south-south inter-organisational learning, from which they drew the conclusion that "collective learning also depends on character-based trust, such as a common cultural identity." In theory, multi-culturalism should play a positive role in bringing diversity to knowledge sharing and learning in networks (Dube & Ngulube, 2012), and Grundel and Dahlström (2016, p. 969) argued that the "democratisation" of the innovation process is critical for a quadruple helix innovation model to succeed.

Trust and intellectual property.

As evidenced in the interviews, another area where trust is an issue is around IP, which, together with ownership of knowledge, is a significant topic in innovation discourse and praxis

(Greenhalgh & Rogers, 2007). If not adequately dealt with at the onset of a collaboration, relationships between actors can be damaged and knowledge exchange obstructed. This was illustrated by Prof. Sithole (Interview 26, August 9, 2017), when he commented on an experience, he had at the CSIR.

> "Even if you have the patent, if somebody else breaks it, we [the CSIR] don't have the resources to fight it; it is difficult. The CSIR was burnt badly with cell phone battery technology developed at the CSIR … so far, I think they've got less than R10 million back. They haven't got much for it, yet that's the thing they developed."

IP is clearly a concern, especially given industry-academia evidence that this can increase a company's rate of generating patents, development of new products, increased share price (Bouraoui et al., 2011), and competitive advantage (Brinkley, 2006; Kraak, 2007; Parveen et al., 2016; Tallman et al., 2004; Zheng et al., 2016). Issues of ownership can arise if the innovation is successful financially, or when an entity in the collaboration tries to monopolise and restrict access to finances (Brinkley, 2006). In their study on academic-business research collaborations in Europe, David and Metcalfe (2010) found that the possession of knowledge and protectionism was a prohibitor for this type of collaboration. The CSIR has dealt with this potential predicament by either "doing IP through license, or we keep the technology in-house" (Prof. Sithole, Interview 26, August 9, 2017). An implication of keeping technology, knowledge and learning in-house is that it becomes *locked-in*. It is not shared and could hold back a larger-sectoral shift towards the development and use of, in the case of this study, biorefinery technologies. It is argued that this type of lock-in is a manifestation of modern industrial economies, in which dominant technologies are reinforced and outsider access or contribution is restricted (Brinkley, 2006; Kemp-Benedict, 2014; Oestreicher, 2012; Tallman et al., 2004)

These dynamics of trust and collaboration are a challenge for this study. This is because my hypothesis is that, for the South African forestry-products biorefinery innovation system to be effective and efficient (i.e., enabling equitable knowledge exchange), it needs to include civil society. From the perspective of civil society knowledge, I believe that this relationship challenge can be overcome. There have been instances within the forestry sector when collaboration has benefitted both industry and civil society. For example, WWF-Mondi's Wetlands Programme, which has existed for over 25 years (University of Cambridge, 2017; WWF-SA, 2016), is a solid partnership between civil society and industry. This relationship was well articulated by Morné du Plessis, the Chief Executive Officer of WWF-SA. In a publication celebrating the partnership, he stated "the WWF-Mondi journey is a story about people and the incredible impact we can make when we come together, in all our diversity, and put our ideas, resources and energy to good use" (WWF-MWP, 2016, p. 4).

8.1.3 Cognitive dimension

The cognitive dimension includes the shared language, codes and narratives (or lack thereof) within a knowledge network (Bonfim et al., 2018; Nahapiet & Ghoshal, 1998). Nahapiet and Ghoshal (1998) suggested that these cognitive commonalities expedite knowledge transfer due to an enhanced understanding between the individuals within the network. If advanced, it is an indicator of the strength of the relationships between individuals, as cognitive variables are developed and strengthened over time. This is highlighted in relation to the knowing of each other and the longevity of relationships, particularly between industry and academia.

For the purposes of this study, I wish to focus on the commonalities of understanding of the biorefinery concept in the South African forestry-products biorefinery network. The reason for this focus is that it became apparent during the analysis of strategies, policy and the interviews that definitions and understanding of the concept varied. Given that the innovation system is formative and operates in pockets of activity, the question arises as to whether this variation in understanding inhibits collaboration and biorefinery uptake.

Table 12 highlights some of the variances in definitions and descriptions identified through leverage professional transcript analyses. Appendix F provides a full list of all the definitions and descriptions provided.

Table 12: Examples of the varying definitions of biorefinery technologies provided by the leverage professionals

Leverage professional	Organisation	Description of biorefinery technology or products
Industry		
Dr Johan de Graaf	**Hans Merensky Holdings**	*He noted his definition is from the perspective of a sawmiller and seeing value in byproducts:* "Any byproducts of high value that allows us to enter into higher markets. Maybe substitutes … new value chains … like crystalline cellulose, which can be used in dairy products to clothes to cell phone screens. It can have a wide application. Other things like low-calorie sugars – xylitol." (Interview 10, September 6, 2018)
Michael Peter	**Forestry SA**	"Biorefineries produce a variety of products such as biopolymers and chemical cellulose. … A biorefinery is any facility that optimises the possible range of products that could be produced from a given feedstock, as opposed to a processing plant that is unidirectional, in that it has two or three given product lines. You could put all your black liquor through the recovery boiler, all your sawmill's fines into a plant. … the optimal use of the entire feedstock that comes into the biorefinery." (Interview 16, September 5, 2018)
Dr Nelson Sefara	**Sappi**	*From the perspective of having generated and applied in-house knowledge on biorefineries*: "A biorefinery is any technology that attempts to extract new material and new products that are outside of the general scope of beneficiation. The ways that we use wood are for structural purposes or for making paper, which is probably the biggest use. Anything outside of this, you are now making secondary products, either by adding chemicals or even classifying energy products from wood, e.g., firewood. Other products include bio-oil and polymers. … Biotechnology is the mechanical or biological way of fermentation, and there are chemical conversion processes. … other processes include taking waste or sludge from our existing operations and extracting from them chemicals or manufacturing them into other products, which are considered biodegradable." (Interview 19, September 3, 2018)
Jaco-Pierre van der Merwe	**York Timbers**	"To transform wood or timber into something that is usable. A refinery means basically to refine something, and so I think a biorefinery is not necessarily limited to wood. I think it's anything that's biological. It can be food waste; it can be timber. Byproducts can be used." (Interview 22, September 25, 2018)
Government		
Steven Ngubane	**IDC**	"It is a chemical process aimed at extracting valuable nutrients from a wood-based material. This will probably vary in other sub-value chains in the industry, for example sawmilling. The conventional product there is structural industrial timber, and the byproduct will be sawdust. That becomes the raw material for the biorefinery process.… It is a chemical process aimed at advancing the benefits that can be derived from the value chain over and above the conventional understanding of the wood-based industry." (Interview 4, August 2, 2018)

Leverage professional	Organisation	Description of biorefinery technology or products
Dr Konanani Rashamuse	**DST**	*He has an in-depth understanding of the biorefinery value chain, having developed and worked on the DST's biorefinery strategy (yet to be published):* "Typically, a value chain for a biorefinery has an upstream (such as primary agricultural production). … First-generation biorefineries refer to starch-based feedstock, and then you have second generation biorefineries, which look at lignocellulosic ethanol, and third generation, with multiple feedstocks and multiple products." (Interview 7, September 5, 2018)
Academia and research institutions		
Prof. Johann Görgens	**Stellenbosch University**	"There's a list of fifty products. When we talk about biorefineries, pelletisation is a simple technology. In biorefineries, I'm talking about a lot more complicated technologies to make, e.g., succinic acid. … It's an industrial facility, which means a paper and pulp mill or a sugar mill or Sasol. … the easiest way to define a biorefinery is to look at the products, say producing ethanol. This is a conventional technology, but it's still considered a biorefinery to people who produce ethanol." (Interview 29, September 18, 2018)
Prof. Bruce Sithole	**CSIR**	"[W]ood comprises hemicellulose, lignin, cellulose … if you are making paper, all you want is the cellulose, the rest is considered waste. … hemicellulose sugars can be extracted and converted into something else, for example, xylose, and from there into xylitol. … from pine, pine oils can be extracted. … from sawdust, nanocrystalline cellulose, so there is no more waste. Extracting maximum value from the tree. … a byproduct of producing pulp is lignosulfonates, which are being used to make binders for …. road surfacing. So, in the case of biorefineries, you are refining it into different types of products, the same materials and chemicals that you'd obtain from oil and coal, you obtain them from …. wood biomass. … it is taking biomass and refining it into different products, chemicals and materials. … the higher value materials are chemicals, and these are obtained in small quantities." (Interview 27, August 1, 2018)
Civil society		
Bhavna Deonarain	**TIPS**	*She acknowledged that she is not an expert in this field but has a basic knowledge from carrying out research on the topic:* "It uses feedstock, such as maize or sugar or byproducts or waste to produce a spectrum of chemicals or composites. … With a biorefinery, you'd be able to maximise the use of a tree and extract the fibres. From each different crop, there are different processes and different outputs." (Interview 35, September 7, 2018)
Saliem Fakir	**WWF-SA**	*He noted he is not competent to provide a comment on uses other than biofuel, and that he is not a biorefinery expert:* "My understanding of a biorefinery is that you can have a process which is governed by the biological activity of the material; in this case, that could be micro-organisms, like specific types of bacteria. It could be things like yeast, fungi … using microbiological life to generate a chemistry pathway that is able to generate products … beer, medicines, future bioplastics, fuel like ethylene, etc. The biorefinery is the physical thing, like a bioreactor. It is the real science and the choice of the microbial life one selects, and you can do it in the classical way where you don't do any genetic engineering and you experiment with microbes … or you can do genetic engineering. … you create a bioreaction." (Interview 36, August 17, 2018)

Table 13: Examples of biorefinery definitions in relevant South African bioeconomy and biorefinery documents

Text	Definition or description of biorefinery
A biorefinery approach to improve the sustainability of the South African sugar industry (Gorgens et al., 2015)	"Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy. The biorefinery concept embraces a wide range of technologies able to separate biomass resources (wood, grasses, corn, sugarcane, etc.) into their building blocks (carbohydrates, proteins, triglycerides, etc.), which can be converted to value added products, such as materials, biofuels, chemicals and electricity."
Biorefinery research consortium (SA Department of Science and Technology, 2018a)	"[T]he beneficiation of waste byproducts from forestry, timber, pulp and paper industries, such as sawdust, finding alternative and innovative uses for the waste and diverting it from landfills."
CSIR (2017)	"A biorefinery entails using wood biomass to extract maximum value from the wood with minimal wastage. Thus, in addition to traditional forestry, tree, pulp and paper products, value is extracted from waste and byproducts to produce high-value chemicals and other products that would help to revitalise the industry."
Sappi media release celebrating their 20-year partnership with Borregaard (Administrator, 2019)	The LignoTech plant "was designed to generate revenue from a previously-unused component of the effluent stream from Sappi's Saiccor mill. These are used as binding and dispersing agents in a wide range of agricultural and industrial applications."
South African biorefinery research platform (SA Department of Science and Technology, 2018b)	"Valorisation of biomass and biomass-waste."
South Africa's Bioeconomy strategy (SA Department of Science and Technology, 2013)	"In a low-carbon future, biorefineries (comparable to petroleum refineries) will use renewable biomass to produce bioenergy, biomaterials and bio-based chemicals. An industrial bioeconomy should develop an integrated biorefinery concept for the co-production of food and non-food (feed, chemicals, materials and energy) to facilitate the transition from fossil resources to renewable bioresources. … An integrated biorefinery will provide cost and energy efficient ways to make optimal use of biomass for several purposes. Biomass could be used as building blocks for the generation of high-value products such as proteins, fine chemicals, carbohydrates and oils, which create opportunities for a viable industrial bioeconomy."

The descriptions and definitions provided by the leverage professionals and selected documents have commonalities. Nearly all referred to biomass as the primary feedstock for biorefineries, which in turn is converted into higher-value products. The variance in the type of products listed illustrates the level of involvement or understanding of the leverage professional and the document focus. It is interesting to note that individuals who engage with Prof. Sithole of the CSIR use similar language and provide a similar list of products. The same applies to those in the *Waste to Wing* project, which has a bias towards biofuels, therefore S Fakir and T Bole-Rental of WWF-SA and A Baldo of RSB focused their descriptions on biofuels. Where there was a notable distinction, was in the definitions provided by S Fakir, and J Lyons of GreenCape, who both described the process as a biological or microbial one. This reflects, in the case of J Lyons, his microbiology education background.

Another interesting finding is that, while there are commonalities in definition and interpretation, the discourse is very technical. As a result, some of the leverage professionals felt their responses might not be adequate (for example, S Fakir or B Deonarain), or that some of the terminology used would be "over their heads" (P Saayman, Interview 18, August 7, 2019).

8.2 Evidence of knowledge generation and acquisition within the knowledge network

Knowledge generation, more specifically learning-by-doing, is a core component of systems of innovation discourse (see for example Borrás & Edquist, 2014; Brenner, 2007; Jensen et al., 2007; Lundvall & Lorenz, 2007). This is recognised within the context of two main knowledge production paradigms: codified and tacit. As suggested by Lundvall and Lorenz (2007) and Jensen et al. (2007), codified knowledge emphasises science, technology and innovation as the mode of learning; and tacit knowledge emphasises how, in a dynamic environment, organisations and individuals become learning orientated to adapt and innovate by "doing, using, experimenting and interacting" (Lundvall & Lorenz, 2007, p. 23).

From a TIS perspective, learning-by-searching and learning-by-doing are recognised as important components of the innovation process. However, the analytical framework provides a narrow set of indicators to identify and assess the level of knowledge generation and learning within a TIS. For example, indicators include the number of R&D projects, investments in R&D and patents relating to an innovation topic (Hekkert et al., 2007; Uriona & Vaz, 2017).

Therefore, to assess the types of knowledge generated and acquired within the South African forestry-products biorefinery innovation system's knowledge network, I drew on Nonaka and Takeuchi's (1995) framework. This framework categorises codified knowledge into symbolic and conceptual, and tacit into experiential and routine knowledge. Table 14 presents examples of the different modes of knowledge generation and acquisition cited by the leverage professionals against these parameters. Their answers were prompted by questions on their employment and educational pathways, and the value both modes of knowledge production had in their day-to-day work. They were also asked how they acquired knowledge, for example, from reading articles through to learning from their colleagues.

Table 14: Knowledge modes identified and applied by the leverage professionals[84]

Codified knowledge		
1. Systemic knowledge		
Definition: Systematised and packaged knowledge. Pre-tested and paradigm-based, using objective scientific methods. It includes know-what, such as scientific results, specifications, manuals, databases, patents and licences; and know-why, which means to understand the context of an innovation.		
Examples	**Leverage professional**	**Actor group**
I'm a firm believer in attending conferences and seminars.	Dr Längin, Mondi	Industry
A PhD allows you to approach problems using a scientific method and to solve them. To establish a knowledge base.	Dr de Graaf, Hans Merensky Holdings	
Through an MBA I was able to tune into financial aspects.		
Research and academia have put me in a good place. My forestry academic background has given me a bigger picture and how to understand it [the sector].	Dr Heath, Forestry SA	
I did an MBA to understand business and economics and to give me a better rounding, including strategy and global trade. It was useful.	M Peter, Forestry SA	
Biomass was part of my MSc.	C Smit, SAFCOL	Government
Doing my Environmental Management Diploma introduced me to good researchers.	H Nuwarinda, NCPC	
I'm very applied, and work with true researchers – we need them.	Dr Morris, ICFR	Academia and research institutions
My PhD provided a foundation for technical research.	Dr Trotter, CSIR	
My education in Zimbabwe prepared me well for academia.	Prof. Sithole, CSIR	
Through studying, I realised a stream of work called biotech.	J Lyons, GreenCape	Civil society

[84] Sources: Al-Laham et al., 2011; Bresnen & Burrell, 2013; Dinur, 2011; Gibbons, 1998; Hessels & Van Lente, 2010; Jensen et al., 2007; Lundvall & Lorenz, 2007; Muller & Taylor, 2012; Nonaka & Takeuchi, 1995; Piperca et al., 2009; Witt & Zellner, 2007.

Codified knowledge		
2. Conceptual knowledge		
Definition: Articulated through images, symbols and language (semiotics), product concepts, design and brand equity. It also includes perceptions held by customers and employees of an organisation.		
Examples	**Leverage professional**	**Actor group**
No obvious examples provided by the leverage professionals mirrored this category. If this research had adopted a symbolic interactionist perspective, this type of knowledge generation would have been clearly identified.		

Tacit knowledge		
1. Experiential knowledge		
Definition: It incorporates know-how, such as individuals' skills to perform dynamic problem-solving, and practical experience; and know-who, which refers to the relationships and interactions between actors and individuals. R&D is mission oriented. Softer dimensions, such as caring, love, personal energy, emotion, attitude, thoughts, passion, tension and trust are encapsulated in experiential knowledge.		
Examples:	**Leverage professional**	**Actor group**
The Kimberly-Clark performance management model encourages the development of softer skills, for example, leadership.	F Hansen, Kimberly-Clark	Industry
Hopefully, through training on site, we can retain people longer.		
It's good to go and see things for yourself to connect the dots.		
I learnt on the job, on the hoof.	G Trebble, independent	
I draw on my property background to take things to scale.		
Mentoring is important.	Dr Längin, Mondi	
I learn so much from people in the company, for example, corporate governance.	Dr de Graaf, Hans Merensky Holdings	
I learn while on the job.		
I started at LignoTech when the plant was being built. I learnt a lot how to produce the product and now understand how the product is applied and can respond to customers' challenges – it's the best type of learning.	H Reddy, LignoTech	
Jumping around different positions in the company, you learn different things – you learn the entire business.		
All the things I know about the forestry industry, I've done.	Dr Sefara, Sappi	
I've built a sawmill from the ground up – that's where my learning comes from. I've learnt through experience.	P Saayman, Evergreen Timbers	

Tacit knowledge		
A lot of my knowledge I have now is based on personal research and working with the RSB.	A. Baldo, RSB	
1. Experiential knowledge continued…		
I've tried lots of things many times – things physically impossible.	M Nash, PAMSA	Industry continued…
Having government, industry and academic experience and understanding how each works is invaluable – few people can talk from all these angles.	Dr Heath, Forestry SA	
I bring my experience of working in the field and in management into my work.	R Southey, Sawmilling SA	
We are exposed to a lot of things when we talk to the CSIR.	K Ross, SAFCOL	Government
If you see [observe], you can make informed decisions.		
Students doing work-integrated-learning in industry have an almost 100% take-up in industry.	Dr Pauck, DUT	Academia and research institutions
Master's students funded by PAMSA do mill-based projects.	I Kerr, UKZN	
I learnt a lot from the Sasol guys when servicing their boilers.		
The research we do is directed research: It is not for the sake of it, it is to solve research problems.	Prof. Sithole, CSIR	
Working as a consultant made me to deal with different people and different world views.	Dr Trotter, CSIR	
Don't get formal training in facilitation; I learnt on the job and learnt fast.		
Through jobs, I have been exposed to environmental studies and heavy industry.		
Because of my insights and research across sectors, I can apply these across sectors.	J Lyons, GreenCape	Civil society
On-the-job learning of business and market-related has provided understanding and right questions to ask		
Trips have provided access to the right people.		
I learn from people I speak to.		
I started in the Land and Agriculture Centre as an intern and worked my way to Director and learnt on the way.	S Fakir, WWF-SA	
I've read a lot and am self-taught.		
I did a lot of hands-on and practical learning during my master's, which was useful.	T Bole-Rentel, WWF-SA	
I came to the SDCEA with no experience and worked my way up as I got experience.	B Mthembu, SDCEA	
I learnt much through mentorship – on trips, talking to people.		
Site visits give me exposure.		
Mapping out problems with communities.		

Tacit knowledge		
2. Routine knowledge		
Definition: Routine knowledge is embedded in actions and practices that are internalised over time. It includes know-how, such as daily operations, organisational routine and structure.		
Examples:	**Leverage professionals**	**Actor group**
I believe a good process engineer training programme with good guidance and structure from our senior engineers provides a more rounded engineer than a 2-year master’s. I prefer students on site and exposed to industry.	F Hansen, Kimberly-Clark	Industry
I’ve been at Sappi for 30 years and have developed during this time.	Dr Kanzler, Sappi	
I’ve been in the business for 30 years.	M Peter, Forestry SA	
What is interesting about my journey is the stuff I’ve learnt along the way. I’ve picked up a lot of things and know how to do my job because of everything I’ve learnt.	S Kalan, DST	Government
During my time at Drew Chemicals, I learned a lot about water treatment. It was hugely useful for furthering my career.	I Kerr, UKZN	Academia and research institutions
Going to Europe and speaking in the EU parliament gave me the ability to talk in South African parliament, and to negotiate.	B Mthembu, SDCEA	Civil society
I’ve experienced pollution first-hand.		

The examples provided in Table 14 suggest leverage professionals have a leaning towards tacit knowledge production and learning, which is predominantly obtained through experience and routine. Those that have held their positions for the longest alluded to their cumulative knowledge over time. For example, M Peter (Interview 16, September 5, 2018), of Forestry SA, said he draws on his 30 years' experience in the forestry sector as integral to formulating his knowledge. Dr Kanzler (Interview 13, August 7, 2018), a scientist at Sappi, also developed his knowledge over his 30 years at Sappi. Nearly all leverage professionals reflected on the value and importance of knowledge generated through experiential learning. They did so through the use of words such as "learnt on the job", "drawing on my experience", "I've tried many things", and "I've learnt along the way".

Regarding codified knowledge, leverage professionals who had a formal education referred to the value of codified knowledge and its application in their current roles. However, Dr Maseko of AfricaBio, R Southey of Sawmilling SA and T Bole-Rental of WWF-SA all cautioned about the potential meaninglessness of studying for the sake of study, as illustrated by their personal experiences.

> "I decided to do [PhD] research that is relevant to the industry, with the view that I will hopefully get a job in the industry. I can tell you, I spent more than fifteen years in the forestry industry, doing all sorts of work, but never got hired in any form in the area that I studied in." (Dr Maseko, Interview 38, September 20, 2018)

> "My formal education is hopeless for understanding the modern biorefinery." (R Southey, Interview 20, September 19, 2018)

> "I didn't know what to do with my undergraduate degree." (T Bole-Rentel, Interview 33, August 31, 2018)

In the main, leverage professionals found value in both codified and tacit knowledge generation. However, in some instances, they favoured one over the other, for example, Dr Sefara of Sappi, noted that "70% of what you learn is on the job" (Interview 19, September 3, 2018). Yet, on the other end of the spectrum, Dr Längin of Mondi declared he was a firm believer that having a formal education is critical. He maintained he did not like employing "side-line" people (aka those not appropriately qualified) (Interview 14, August 6, 2018). The interaction between both modes is discussed further in Section 8.2.2.

8.2.1 Work-based learning and work-readiness of post-graduates and new workplace entrants

One of the most significant areas of concern raised by industry leverage professionals was that of work-readiness, particularly that of post-graduate students as new, young entrants inducted into the world of work. It was clear to them that having an academic qualification does not align with being work-ready, as illustrated below:

> "We find that people can come into the organisation with certain types of degrees and certifications but, when they actually step into the plant itself [at LignoTech], they really battle to grasp the concepts, and so it does take time [to train them]." (H Reddy, Interview 17, August 6, 2018)

> "For me, [a] master's is a big research project. So, the student can crunch numbers but, when they come here [Kimberly-Clark], and I have a PhD here that is a brilliant, clever guy … it still takes them a year to start showing results." (F Hansen, Interview 11, September 4, 2018)

Given the importance of work-based learning to industry, academic institutions provide opportunities for post-graduate students to go into industry to conduct research and acquire knowledge. This gives students an opportunity to obtain tacit knowledge. This is when formal learned knowledge, such as university knowledge, is used and experienced in the workplace (Bouraoui et al., 2011; Kruss & Visser, 2017). It provides a platform for knowing and relating why and how a solution or practice is adopted. This is attributed to the student or new entrant learning and developing through work-based practice. (Guile & Griffiths, 2001; Johnson et al., 2002).

This "directed research", as referred to by Prof. Sithole (Interview 26, August 9, 2017) in the CSIR, aids the identification of innovative solutions to solve problems in industry. I Kerr of UKZN went further to suggest that the sector needs "people who can problem-solve at the level of master's, who've done research projects …. We want to increase that skill." (Interview 30, August 7, 2017). Dr Pauck (Interview 24, August 8, 2017) of the DUT, built on I Kerr's comment in his explanation of what the link between academia and industry means for the student:

> "The initial concept was that students would be recruited by the different mills: that they would study in the mill situation, they would be mentored by the mills, and that we would supply them with theoretical material out of the university."

This approach is referred to by Guile and Griffiths (2001) as one that focuses on enabling students to transition to the labour market. Both they and Miller et al. (1991) suggested that this not only allows the new entrant to learn the how and why of work but also to become a more independent adult.

The identification of the types of projects (or directed research) selected for the students, and where they are placed, is a well-formulated process, coordinated by PAMSA in consultation with its Executive Committee. This is made up of directors of various pulp and paper companies, universities and the CSIR (Dr Pauck, Interview 24, August 8, 2017; Prof. Sithole, Interview 26, August 9, 2017). The process was described as follows by I Kerr (Interview 30, August 7, 2017) of UKZN:

> "Mondi, mPact, Sappi, Kimberly-Clark, Twinsaver, they will decide for 2018 … Sappi will take two master's, Mondi will take two master's, Mpact will take one and so on. So, they choose students to do master's projects."

Industry therefore plays an important role in dictating its requirements. Academia and research institutions respond by providing students and undertaking complementary theoretical and research instruction. In addition, industry may require people with specific skills and capabilities, and in response, academia will develop curricula or programmes to meet industry's needs (Dr Pauck, Interview 24, August 8, 2017).

It is also through PAMSA that funding is sought for post-graduate students from the Fibre and Packaging Manufacturing Sector Education and Training Authority (FP&MSETA). The focus of this funding is to support work-integrated learning (I Kerr, Interview 30, August 7, 2017; Dr Pauck, Interview 24, August 8, 2017). Funding of work-based learning studies, for example, a 2-year master's, is sponsored by one of the pulp or paper mill companies.

This industry-directed approach can have negative consequences, however. For example, when their areas of focus or requirements change, it can affect the supply of funding or mentoring of students, as illustrated by Dr Pauck (Interview 24, August 8, 2017) of DUT:

> "It started with a huge momentum, but then it slowly broke down because the mills didn't really want to mentor these guys [the students]. A mill would have recruited say six students, who would arrive every day to study. A lot of mills, I don't know, they just didn't want to do that."

He also suggested that on-site health and safety had become an issue:

> "[T]hey [the mills] don't want a whole lot of students wandering around for three weeks because they also have health and safety concerns. … if they get injured, they're responsible. So, the companies have this legal burden. They don't want to take the students. Well-intentioned safety legislation, in this case, stifles this sort of stuff [opportunity to learn via work-based learning]. (Dr Pauck, Interview 24, August 8, 2017)

Work-based learning and cultivating experience through doing was not unique to the industry, academia and research institution consortium. It was also evidenced within the civil society actor group, such as in the much-valued mentoring relationship between W. Menne, the Director of Timberwatch, and B Mthembu of SDCEA. He explained how he learnt a lot from W. Menne as they spent time travelling around the country, working together on environmental awareness-raising missions and visiting plantations (B Mthembu, Interview 39, August 31, 2017; Menne, 2016). Through Menne's mentoring, B Mthembu and his colleagues at the SDCEA also improved their research methods (such as community surveys) and awareness-raising skills and capabilities. In addition, the connection gave B Mthembu access to W. Menne's network of environmental practitioners, who benefitted the SDCEA through the exchange of knowledge.

For B Mthembu, this teaching-learning mentoring in his work environment proved beneficial for his personal development. Trust, value, respect, and world-view expansion were key elements in this relationship. These correlate with Darling's (1984) parameters of mentoring, which included career counsellor, teacher, feedback giver and eye-opener, attributes that B Mthembu clearly assigned to W. Menne. Sadly, W. Menne died during this study, much to the loss of B Mthembu who, in our second interview, regularly reiterated the value of W. Menne's mentoring and time with him.

8.2.2 No one mode rules

With leverage professionals alluding to the value of both codified and tacit knowledge, this raises the issue of the interaction between both modes of knowledge. It also raises a question about the value of such a discussion. As noted by Johnson et al. (2002), a simplistic distinction between the two modes is problematic, particularly with regard to the practical application of the modes, and the dynamic relationship between tacit and codified knowledge (Adler, 1996).

The separation of codified and tacit knowledge is all too common (see, for example, Ancori et al., 2000; Borrás & Edquist, 2014; Sanchez, 2004). Both mechanisms of generating knowledge were identified as being of value to the leverage professionals. This research suggests there is room for both. It also recognises that knowledge generation is not a linear process from undertaking a degree (codified) through to learning on the job (tacit). This stance is supported by Borrás and Edquist (2014) and Sanchez (2004). Sanchez (ibid., p. 17) calls for a "synthesis of tacit and knowledge management approaches … to create a hybrid". It is a circular or spiralling process whereby codified knowledge is accessed throughout an individual's working career. Dr Kanzler of Sappi believed the two modes should be balanced. He suggested that "once you have got the qualifications and then you develop five to ten years of experience, that's when you really start to become a lot of value because you have developed that insight. You've got to have that balance [academic and practical experience]" (Dr Kanzler, Interview 13, August 7, 2018). This was supported by Guile and Griffiths (2001), who drew on the work of Beach and Vyas (1998) and Engeström (1996) to inform their work on learning through work experience. They suggested that higher education curricula should "take work in all of its forms as the basis for the development of both knowledge (historical and scientific), skills (intellectual, technical, practical and communicative) and identity (the ability to act as a boundary crosser)" (Guile and Griffiths, 2001, p. 114). The concept of a boundary spanner or crosser is discussed further in Chapter 9.

S Fakir of WWF-SA[85] made a remark similar to Dr Kanzler's. More than all the others interviewed, he is a seeker of knowledge. He seeks it out to inform advocacy strategy and to critique economic and topic-based paradigms, such as the bioeconomy. He asked, "Do you

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[85] Saliem Fakir is Head of WWF-SA's Policy and Futures Unit. The aim of the Unit is to "try to get a sense of things in the future and mostly in the technology space." The Unit is also a policy research programme on the food, energy and water nexus. He provides leadership in policy advocacy and stakeholder engagement, such as government, labour unions, civil society and business. In addition to his role at WWF-SA, he is also the Chair of GreenCape's Board of Directors, and Interim Executive Director for the African Climate Foundation.

educate people and expect them to gain sophistication, or should they learn by trial and error?" He considered that "people must be able to make mistakes and society must encourage such mistakes." (S Fakir, Interview 36, August 17, 2018). In conclusion, he reflected*:*

> "I'm a strong believer that the route to education is not just about going to study at university. The root to education comes from a belief in being able to lead a meaningful life and that one way of doing that is to enhance one's cognitive capacities, and you can choose to do it formally, you can choose to do it informally. Part of that enhancement of cognitive capacity is doing something with it. That is where I think work and doing things, and learning are integral … I'm not against formal education, but I think the fanaticism about having a degree to me is meaningless … I want to know what they [the people I employ] think, what's their interest … and quiz them on their technical knowledge." (S Fakir, Interview 36, August 17, 2018)

The findings also respond to the work of Griffiths and Guile (2003), who explored the relationship between work experience, learning and knowledge. They referred to this relationship as "connectivity" (ibid., p. 56). They also dismissed the separation of the knowledge modes. As practised by PAMSA's university-industry model of work-based learning, Griffiths and Guile (2003, p. 64) suggested the benefit to the students is that they "mediate their understanding of the different components of a specific body of knowledge [codified]". By doing so, they "develop a more connected and deeper understanding of the world" (ibid., p. 64). (See Chapter 5 for a theoretical underpinning of the connection and combining of codified and tacit).

8.3 Dynamics of the knowledge transfer interface and mechanisms of exchange

This section explores in more detail the dynamics and characteristics of knowledge exchange and diffusion in the biorefinery innovation system's associated knowledge network. It assesses first the types, and then the mechanisms of knowledge identified.

Gosselin et al. (2018, p. 390) suggested three types of knowledge transfer within a network or between individuals:

- *Trickle-down interface*: a linear model where researchers produce research and users adopt the findings of the research with little effort

- *Transfer-and-translate interface*: where researchers try to translate their results in a comprehensive way, and users of the research test the results for feasibility and relevance
- *User-push interface*: users commission researchers to produce knowledge on topics of interest and worth to them

While all three forms were identified in the knowledge network, the *transfer-and-translate* and *user-push* interfaces were the most identified. Research undertaken at the CSIR's biorefinery facility and by post-graduates via the PAMSA programme exemplifies the *transfer-and-translate* type of exchange. Research is undertaken to test the feasibility of an innovation or process but with the emphasis on its ultimate application in industry.

According to Gosselin et al. (2018), this method of transfer requires capable individuals to transfer and translate scientific results effectively to allow knowledge sharing and contextualisation. This is a recognised skill required for an effective innovation process. It was not possible to assess the effectiveness of this approach in relation to the CSIR's demonstration facility. This is mainly because the facility was only launched in March 2018 (SA Government, 2018a), and it is too early to evaluate its impact.

The *user-push interface* was widely identified and cited by the leverage professionals. Two notable examples stand out: the first is WWF-SA's focus on aviation biofuels. Having identified biofuels as a bioeconomy opportunity for the country, the *Waste to Wing* project was initiated, with the intention to produce knowledge to identify biofuel opportunities and to catalyse uptake. The second example is PAMSA's engagement with the pulp and paper industry to identify areas of research needed. This research is then undertaken by engineering master's students and benefits the hosting company.

Gosselin et al. (2018) noted risks associated with this approach, such as that the perceived needs of individuals (or organisations) in the network may prevent certain types of research being undertaken. In other cases, research that might critique or ask new questions of the proposed research could be neglected. This insight firmly links to the concepts of knowledge lock-in and of trust between individuals and entities, which has been alluded to previously.

To assess the mechanisms of knowledge exchange, an adaptation of Dinur's (2011) taxonomy of knowledge transfer mechanisms was used. Applying this taxonomy to the leverage professional transcripts, the three most common mechanisms were identified: (a) *documentation/manual/codification*; (2) *training/presentations/face-to-face interaction*; and (c) *hands-on practice/inclusion in decision-making* (see Table 15).

For most leverage professionals, undertaking R&D, reading or contributing to written articles, and accessing internet-sourced information are the most prominent forms of *documentation/manual/codification* knowledge transfer. The most common forms cited for *training/presentations/face-to-face* interaction are discussions and meetings, having conversations, networking, attending events and giving presentations. For *hands-on practice/inclusion in decision-making* working on projects together is the most prominent mechanism.

There are some nuances to the mechanisms used, however. For example, sitting on forums and professional group membership were important mechanisms for transferring knowledge. This was particularly evident for industry, academia and research institution leverage professionals. As acknowledged elsewhere in this chapter, the secondment of individuals from industry into academia is a notable characteristic of this knowledge network. In addition, short-term local and international visits were highlighted by several leverage professionals as a valuable avenue for learning.

It should be noted that this assessment is based on the analysis of interview transcripts for an indication of the main forms of knowledge exchanged and used by the leverage professionals. Although it is recognised that the leverage professionals are likely to adopt mechanisms other than those listed, they did not cite or provide evidence of these during the interviews.

Table 15: Mechanisms of knowledge acquisition and exchange cited by the leverage professionals

Document, manual, codification	
Evidence of use	**Leverage professional citings, by actor group**
Research and development (R&D)	**Industry**: F Hansen, Kimberly-Clark; Dr Längin, Mondi; Dr Kanzler, Sappi; Dr de Graaf, Hans Merensky Holdings; H Reddy, LignoTech; J-P van der Merwe, York Timbers; Dr Sefara, Sappi; P Saayman, Evergreen Timbers; M Nash, PAMSA; Dr Heath, Forestry SA; A. Baldo, RSB; R Southey, Sawmilling SA **Government**: K Ross, SAFCOL; C Smit, SAFCOL; S Ngubane, IDC; T Nyanzunda-Kadzombe, DTI; Dr Rashamuse, DST; H Nuwarinda, NCPC; S Kalan, DST; G Barnes, DEA **Academia and research institutions**: Prof. de Koker, DUT; Dr Morris, ICFR; Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR; Prof. Godfrey, CSIR **Civil society**: S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; B Mthembu, SDCEA; J Lyons, GreenCape; B Deonarain, TIPS
Benchmarking	**Industry**: Dr Längin, Mondi; P Saayman, Evergreen Timbers
Data and statistics procurement	**Trade or membership associations**: R Southey, Sawmilling SA
Reporting	**Industry**: Dr Sefara, Sappi **Government**: H Nuwarinda, NCPC **Academia and research institutions**: Prof. Godfrey, CSIR **Civil society**: B Mthembu, SDCEA; J Lyons, GreenCape
Reading and publishing in journals or media or news	**Industry**: Dr de Graaf, Hans Merensky Holdings; Dr Sefara, Sappi; P Saayman, Evergreen Timbers **Government**: T Nyanzunda-Kadzombe, DTI; S Kalan, DST; G Barnes, DEA **Academia and research institutions**: I Kerr, UKZN; Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR; Prof. Godfrey, CSIR **Civil society**: S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; B Deonarain, TIPS
LinkedIn or internet	**Industry**: H Reddy, LignoTech **Government and government delivery vehicles**: Dr Rashamuse, DST; G Barnes, DEA **Academia and research institutions**: Prof. Sithole, CSIR **Civil society**: S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; Dr Maseko, AfricaBio
Attending training sessions or courses	**Industry**: H Reddy, LignoTech **Government**: T Nyanzunda-Kadzombe, S Kalan, DTI; G Barnes, DEA; C Smit, SAFCOL **Academia and research institutions**: DTI; Prof. Godfrey, CSIR **Civil society**: B Deonarain, TIPS
Sharing IP	**Industry**: M Nash, PAMSA
Lecturing or teaching or supervision	**Industry**: R Southey, Sawmilling SA **Academia and research institutions**: Dr Pauck, DUT; Prof. de Koker, DUT; I Kerr, UKZN

Document, manual, codification	
Evidence of use	**Leverage professional citings, by actor group**
Development of course materials or curricula	**Academia and research institutions**: Dr Trotter, CSIR
Input control (aka employing people)	
Evidence of use	**Leverage professional citings, by actor group**
Employing students	**Industry**: H Reddy, LignoTech; Dr Sefara, Sappi **Academia and research institutions**: Prof. Sithole, CSIR
Cultural immersion or long-term visits or employee exchange	
Evidence of use	Leverage professional citings, by actor group
Work-based learning or international trips	**Industry**: M Nash, PAMSA; Dr Heath, Forestry SA **Academia and research institutions**: I Kerr, UKZN; Dr Pauck, DUT; Prof. de Koker, DUT **Civil society**: J Lyons, GreenCape
Short-term visits	
Evidence of use	**Leverage professional citings, by actor group**
Site visits and trips (international and local)	**Industry**: P Saayman, Evergreen Timbers; F Hansen, Kimberly-Clark; G Trebble, independent; Dr Längin, Mondi; Dr Kanzler, Sappi; H Reddy, LignoTech; J-P van der Merwe, York Timbers **Government**: K Ross, SAFCOL; C Smit, SAFCOL; S Ngubane, IDC; H Nuwarinda, NCPC **Academia and research institutions**: I Kerr, UKZN; Prof. Sithole, CSIR; Prof. Godfrey, CSIR **Civil society**: B Mthembu, SDCEA; J Lyons, GreenCape
Training or presentations or face-to-face interaction	
Evidence of use	**Leverage professional citings, by actor group**
Discussions and meetings (internal and external)	**Industry**: F Hansen, Kimberly-Clark; G Trebble, independent; Dr Längin, Mondi; Dr de Graaf, Hans Merensky Holdings; H Reddy, LignoTech; Dr Heath, Forestry SA; M Peter, Forestry SA; R Southey, Sawmilling SA **Government**: S Ngubane, IDC; Dr Rashamuse, DST; S Kalan, DST; G Barnes, DEA; K Ross, SAFCOL **Academia and research institutions**: I Kerr, UKZN; Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR **Civil society**: Dr Maseko, AfricaBio; S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; B Mthembu, SDCEA; J Lyons, GreenCape; B Deonarain, TIPS

Document, manual, codification	
Evidence of use	**Leverage professional citings, by actor group**
Sitting on or belonging to forums and professional groups or associations	**Industry**: Dr Längin, Mondi; Dr Kanzler, Sappi; Dr de Graaf, Hans Merensky Holdings; H Reddy, LignoTech; Dr Heath, Forestry SA; M Peter, Forestry SA **Government**: G Barnes, DEA **Academia and research institutions**: Dr Pauck, DUT; I Kerr, UKZN; Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR
Networking	**Industry**: G Trebble, independent. **Government**: S Ngubane, IDC; Dr Rashamuse, DST **Civil society**: J Lyons, GreenCape; B Deonarain, TIPS
Phone calls and talking or chatting or conversations	**Industry**: G Trebble, independent.; Dr Längin, Mondi; P Saayman, Evergreen Timbers; Dr Heath, Forestry SA; M Peter, Forestry SA; R Southey, Sawmilling SA **Government**: S Ngubane, IDC; T Nyanzunda-Kadzombe, DTI; Dr Rashamuse, DST; G Barnes, DEA; K Ross, SAFCOL **Academia and research institutions**: Dr Morris, ICFR; I Kerr, UKZN; Prof. Görgens, Stellenbosch University; Prof. Sithole, CSIR; Prof. Godfrey, CSIR **Civil society**: S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; B Mthembu, SDCEA; J Lyons, GreenCape
Giving presentations or speaking (internal and external)	**Industry**: G Trebble, independent.; Dr Längin, Mondi; Dr Kanzler, Sappi; H Reddy, LignoTech; Dr Heath, Forestry SA; M Peter, Forestry SA **Government**: H Nuwarinda, NCPC; C Smit, SAFCOL **Academia and research institutions**: Prof. de Koker, DUT; Dr Morris, ICFR; Prof. Görgens, Stellenbosch University; Prof. Sithole, CSIR; Prof. Godfrey, CSIR **Civil society**: S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; B Mthembu, SDCEA
Attending conferences, workshops, roadshows and seminars	**Industry**: Dr Längin, Mondi; H Reddy, LignoTech; J-P van der Merwe, York Timbers; R Southey, Sawmilling SA **Government**: Dr Rashamuse, DST; H Nuwarinda, NCPC; S Kalan, DST; G Barnes, DEA **Academia and research institutions**: Dr Morris, ICFR; I Kerr, UKZN; Prof. Sithole, CSIR **Civil society**: Dr Maseko, AfricaBio; S Fakir, WWF-SA; B. Mthembu, SDCEA; B Deonarain, TIPS
Activist marches	**Civil society**: B Mthembu, SDCEA
Provision of technical support, advice, consultation and feedback	**Industry**: H Reddy, LignoTech; Dr Längin, Mondi; Dr de Graaf, Hans Merensky Holdings; A Williams, Citius Energy; M Nash, PAMSA; Dr Heath, Forestry SA; A Baldo, RSB; R Southey, Sawmilling SA **Government**: S Ngubane, IDC; Dr Rashamuse, DST; H Nuwarinda, NCPC; S Kalan, DST; G Barnes, DEA **Academia and research institutions**: Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR **Civil society**: T Bole-Rentel, WWF-SA; B Mthembu, SDCEA; A Dinan, Fetola Foundation
Mentoring students	**Industry**: F Hansen, Kimberly-Clark **Academia and research institutions**: Prof. de Koker, DUT; Prof. Sithole, CSIR

Long-distance communications or web-conferences	
Evidence of use	**Leverage professional citings, by actor group**
Discussions and meetings (internal and external)	**Civil society**: Dr Maseko, AfricaBio
Hands-on practice or inclusion in decision-making	
Evidence of use	Leverage professional citings, by actor group
Working on project or working with people or collaborative work or integrated learning	**Industry**: F Hansen, Kimberly-Clark; Dr Kanzler, Sappi; Dr de Graaf, Hans Merensky Holdings; H Reddy, LignoTech; J-P van der Merwe, York Timbers; Dr Sefara, Sappi; P Saayman, Evergreen Timbers; M Nash, PAMSA; A Baldo, RSB; R Southey, Sawmilling SA **Government**: S Ngubane, IDC; T Nyanzunda-Kadzombe, DTI; H Nuwarinda, NCPC; S Kalan, DST; G Barnes, DEA; K Ross, SAFCOL; C Smit, SAFCOL **Academia and research institutions**: I Kerr, UKZN; Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR **Civil society**: S Fakir, WWF-SA; T Bole-Rentel, WWF-SA; B Mthembu, SDCEA; B Deonarain, TIPS
Trials and testing or demonstrations or feasibility studies	**Industry**: Dr Längin, Mondi; Dr Kanzler, Sappi; Dr Sefara, Sappi; P Saayman, Evergreen Timbers; A Baldo, RSB **Government**: Dr Rashamuse, DST; K Ross, SAFCOL **Academia and research institutions**: Prof. Görgens, Stellenbosch University; Dr Trotter, CSIR; Prof. Sithole, CSIR
Funding proposal contributions	**Industry**: Dr Längin, Mondi **Academia and research institutions**: Prof. Sithole, CSIR
Contributing to strategy development	**Industry**: M Peter, Forestry SA **Government**: Dr Rashamuse, DST **Academia and research institutions**: Dr Trotter, CSIR
Exposure to industry operations	**Industry**: F Hansen, Kimberly-Clark **Academia and research institutions**: Prof. de Koker, DUT; Dr Pauck, DUT; I Kerr, UKZN

8.4 Competency and capability held within the knowledge network

This section explores the competencies in the South African forestry-products biorefinery innovation system's associated knowledge network. The competencies relate to the development, adaptation, adoption and implementation of biorefinery innovations (Borrás & Edquist, 2013; Cohen & Levinthal, 1990; Jensen et al., 2004; UNCTAD, 2019).

In terms of human capacity, skills and competencies, there was general acceptance by the leverage professionals that the TIS is well-capacitated. Knowledge, skills and competencies adequately developed tend to be high-level skills in management, research, engineering, economics and forestry science. There is a focus on producing master's and doctoral-level students (A Baldo, Interview 9, October 15, 2018; Dr Kanzler, Interview 13, August 7, 2018; Dr Maseko, Interview 38, September 20, 2018; Prof. Sithole, Interview 27, August 1, 2018; C Smit, Interview 8, September 4, 2018).

Given the lack of implementation and uptake of biorefineries in South Africa, this techno-scientific-economic focus on knowledge should be critiqued, even though most literature on innovation recommends technical and entrepreneurial knowledge acquisition as the main reason for individuals to collaborate (OECD, 2011; Sammarra & Biggiero, 2008). This includes the SA government's *Bioeconomy strategy*. While recognising the need for "non-scientific skills" such as business, legal and regulatory knowledge (SA Department of Science and Technology, 2013a, p. 14), it calls for more than these:

> "The training of scientists, engineers and technicians at all points through the entire innovation value chain should be intensified, as well as the development of "technopreneurs", who are vital in developing diverse technologies into innovative products and services at the downstream end of the value chain." (SA Department of Science and Technology, 2013a, p. 3)

> "Developing the bioeconomy will require a range of competencies beyond biotechnology, including information and communications technology (ICT), nanomaterials research and manufacture, bio-entrepreneurship, the social sciences and intellectual property management." (SA Department of Science and Technology, 2013a, p. 7)

This stance perpetuates some innovation and economic development discourse (see Lundvall et al., 2002; Mncwango, 2013; Rickne, 2000), which highlights the need for these skills. However, it neglects other competencies such as policy development, strategic thinking, regulations development, education, finance, and marketing. Marketing knowledge is evident in the South African biorefinery innovation system, but it tends to focus on techno-economic market knowledge. This was highlighted previously as neglecting the role of market knowledge more broadly, and therefore neglecting to consider the relationship between supply and demand for biorefinery products. This point echoes the work of Sammarra and Biggiero (2008), who investigated inter-firm knowledge flows and the issue of neglected market and managerial knowledge in firms. This lack of sound market research and capability within the South African biorefinery space was acknowledged by a number of leverage professionals, including G Barnes, of the DEA and G Trebble, an independent. Both noted that, if market knowledge and application were strengthened, the uptake of bio-innovations could be expedited (Interview 1, October 8 & 18, 2018 and Interview 21, August 20, 2018 respectively).

Since current market possibilities are hindered by an ineffective TIS, the question is whether the sector's emphasis on post-graduate biorefinery research is appropriate. It may result in a glut of over-qualified technically focused individuals in a currently restricted niche sector. Prof. Sithole (Interview 27, August 1, 2018) of the CSIR, in his response to this suggestion noted this could become an issue. However, this could be mitigated if the DST's *White paper for science, technology and innovation and post-school education and training* (Parliamentary Monitoring Group, 2019) is realised. This strategy calls for the creation of a local market for domestic innovations via enhanced public-private partnerships.

In addition, South Africa currently has a scarcity of engineers. For example, chemical engineers were identified in the Chemical Industries Education and Training Authority's (CHIETA) list of scarce skills (CHIETA, 2014). This means that, while the biorefinery sector may currently be niche, these graduates and new work entrants should be able to find employment in the country. Therefore, they should be in a position of readiness when the biorefinery sector expands and is ready to absorb them.

The need for a steady supply of adequately knowledgeable, skilled and competent individuals entering and remaining within the sector does, however, face challenges. Notable amongst these is the exodus of younger entrants who join the forestry-products (particularly forestry) sector but leave after a few years. As highlighted by Dr Längin of Mondi:

> "[I]f you look at most of our young graduates coming through varsity and going into forestry, a lot of these guys are *city slickers*. They don't want to live in rural areas. … They don't necessarily choose forestry as a career. They choose forestry because it gave nice bursaries. … Because often enough they come out of varsity, then they start working, and then they meet their peers back at a school reunion, and some are lawyers and doctors and drive big cars, and here comes a Mondi forester in a double-cab bakkie. The peer pressure is huge for these youngsters. We need to find people who are passionate and have a drive for this type of job. We need to find a way to attract these young people into our business going forward. It is critical." (Dr Längin, Interview 14, August 6, 2018)

Two main reasons were given for the exodus of new entrants: first, financially attractive opportunities overseas or in other sectors, such as banking (Dr Kanzler, Interview 13, August 7, 2018; Dr Längin, Interview 14, August 6, 2018; T Nyanzunda-Kadzombe, Interview 6, September 25, 2018); and, secondly, a millennial workforce that no longer fits the *job-for-life* profile. These newer recruits move from opportunity to opportunity, or project to project (Dr Kanzler, Interview 13, August 7, 2018). They are comfortable moving every three to five years from one company or location to another (Črešnar & Jevšenak, 2019; Landrum, 2017; Ng et al., 2010). What this means for the forestry-products biorefinery innovation system is that government policy and industry ambitions need to mirror contemporary employee aspirations. In this way, they can attract into and retain younger entrants in the workforce.

The exodus of skilled individuals overseas is particularly acute in South Africa and most African countries. It is argued this exodus is due to issues of corruption, safety, a perceived declining higher education system, affirmative action, xenophobia and political instability (Schierup, 2016). This *brain drain* leads to the depletion or loss of intellectual and technical personnel. It can have a negative outcome that impacts the economic and social growth of the country (Kerr-Phillips & Thomas, 2009). However, as noted by T Nyanzunda-Kadzombe (Interview 6, September 25, 2018) of the DTI, this was not seen as too much of an issue for her. What was important for her was, "as long as they return to the sector or the country in the future" with their skills and experience. This statement is supported by research on the role of returnee entrepreneurs in innovation and entrepreneurial development in developing economies (see Li & Xia, 2014; Olafsen & Cook, 2016). However, some authors (for example Moed et al., 2013) suggested that organisations should become accustomed to the trend of skilled individual mobility because mobility is a characteristic of the contemporary work environment, particularly as knowledge is prized and traded globally. This suggestion is highlighted by Luk (2016) who estimated that, by 2022, 42% of the global workforce could be mobile.

This human resource shrinkage has led to a *missing middle* in the South African forestry-products sector. There are not enough experienced or skilled individuals in middle management, as is evidenced by the average age of 46 years for the leverage professionals. This situation was acknowledged by some in the sector, such as Dr Kanzler of Sappi, Dr Längin of Mondi and Prof. Sithole of the CSIR. They reflected upon this in relation to not knowing who had the appropriate skills and knowledge to replace them (Interview 13, August 7, 2018; Interview 14, August 6, 2018; Interview 27, August 1, 2018 respectively). This issue is regularly cited in skills demand studies. It points to the need for improved succession planning (see for example, International Ocean Institute – African Region [IOI-SA], 2018; Theron et al., 2014; Van den Barselaar, 2018). The concern was highlighted in a green skills study on the South African public sector (Ward et al., 2016), and a skills needs analysis for the marine protection and ocean governance sector in the country (IOI-SA, 2018). Knowledge and skill retention are therefore an important consideration for succession planning because it can ensure biorefinery potential is realised as professionals grow with and enter the innovation process, thereby enhancing absorptive capacity.

Given the general scarcity of high-level skills in the forestry-products sector, there is much demand for graduates. This is a challenge for academia and industry, as this situation has resulted, in some instances, in post-graduate students' being employed prior to completing their research. As illustrated below:

> "[T]he company needed the students, so they took them before they completed their master's. What they [industry] should have done is said 'finish your thesis and then we'll employ you'." (I Kerr, Interview 30, August 7, 2017)

> "Before [the diploma], they [industry] were taking matriculants, or Standard 8s and now they have these guys who are studying on site and also working and then they see that the students are better than what they've been getting in the past. They may need an operator, who only needs a matric, but they'll employ the student who is only too pleased to get a job. This was one of the major factors why the UNISA program basically crashed, is the mills were stealing the guys [before they completed their studies]." (Dr Pauck, Interview 24, August 8, 2017)

It is unlikely that this situation will be resolved while the sector has a demand for capable and competent employees. This results in a contradiction between the industry needing work ready individuals, yet universities not having fully educated them in the theoretical foundations of their discipline.

> "As an educational institution, I don't believe it's possible to make somebody work-ready. … yet, I think the expectation is that they [industry] want work-ready graduates. So, they really want a graduate, a qualified person with five years' experience somehow bundled into someone who has the required education. I don't see how you can do that, but that is the expectation." (Dr Pauck, Interview 24, August 8, 2017)

This was illustrated by Dr Kanzler of Sappi, when commenting on the value of tacit versus codified knowledge. He noted, "work verses education is a bit chicken and egg. Industry wants students with experience but won't give them a job because they don't have experience." (Interview 13, August 7, 2018).

Dr Pauck (Interview 24, August 8, 2017) was concerned about student absorption into industry before completing their studies because universities receive government funding based on the number of students they see through to graduation. If students are poached before they finish their degrees, the university does not get its full funding quota. This puts financial strain on the academic institution.

To mitigate some of the situations highlighted above, leverage professionals offered insights as to how human capacity and capability could be improved to catalyse biorefinery potential in the country. For example:

- taking on post-graduate students who they can then employ (F Hansen, Interview 11, September 4, 2018) (see the challenges of this approach discussed above)
- linking all components of the supply chain to realise the biorefinery opportunities (Dr Kanzler, Interview 13, August 7, 2018)
- construction of a skills centre (B Mthembu, Interview 40, August 3, 2018)
- in-house training (Dr Längin, Interview 14, August 6, 2018; K Ross, Interview 8, September 4, 2018)
- providing attractive on-the-job learning opportunities, such as site visits (Prof. Sithole, Interview 27, August 1, 2018)
- good mentoring (F Hansen, Interview 11, September 4, 2018)

8.5 Conclusion

What has emerged from this chapter is that the network that ties individuals and actors together is critical for the transfer of knowledge. These ties, if strengthened, can further enable the forestry-products biorefinery innovation process. There are those in the network who generate knowledge, those who facilitate knowledge transfer, and those who predominately receive and then interpret knowledge to inform decision-making.

Nahapiet and Ghoshal's (1998) framework for analysing the social capital dimensions of inter-firm knowledge transfer proved to be a useful tool for developing an understanding of the functionality of the knowledge network. By adopting this framework, I was able to expand the dimensions and level of understanding of the knowledge network. This would not have possible if I had followed the TIS framework literally.

By assessing the structural and relational dimensions of the knowledge network, it is possible to suggest that the South African forestry-products biorefinery innovation system is made up of intra-knowledge networks within a broader informal network. Each intra-network tends to exchange knowledge between its members. This is most evident in the dominant duo-helix of academia and industry that is facilitated through PAMSA. The type of research to be undertaken by post-graduates is determined within the consortium of predominantly industry and academia. Another strong intra-knowledge network is that of the *Waste to Wing* project, which tends to be siloed, with few extensions into the wider knowledge network. The same applies for the alien vegetation sector, which is disconnected from the traditional forestry-products sector.

From a knowledge diversity perspective, the biorefinery network is not as varied as it could be. It is skewed towards a partnership between industry or academia and, to a lesser extent, government. Civil society is represented by NGOs who tend to operate within smaller, contained knowledge networks, with little recognition from industry and academia.

The unique knowledge network mapping exercise illustrated the centrality of certain individuals and actors. Two individuals featured prominently as sources and generators of knowledge. These were the academics, Prof. Sithole of the CSIR and Prof. Görgens of Stellenbosch University. What does this mean for the knowledge network? It means that the potential exists for insufficient diversity of knowledge in the system. It could mean that there is a bias towards certain knowledge, R&D and biorefinery products. It could also mean a significant loss of knowledge if they leave the network.

Another core group of individuals that emerged as central to knowledge dispersion were those involved in coordinating or facilitating knowledge generation and transfer. This was either through the programmes they run to catalyse innovation, stimulate research or through networking to access information.

Another area of strong relationship was between those in industry and their place of education. This reiterates the emergent themes of trust and knowing of others as key variables for knowledge exchange and generation. Trust emerged as a central issue. This correlates with social capital discourse, which sees trust as central to effective social learning. Without it, knowledge exchange may be hindered. Good examples of lack of trust within the network included knowledge lock-in, which was particularly noted by industry. The lock-in could be due either to IP restricting knowledge exchange, or to an unwillingness to share knowledge that might prohibit competitive advantage in a small South African market.

The other area to emerge in this regard was a mistrust of civil societies' knowledge, seeing it not equitable to industry and academic knowledge. Analysis of the interview transcripts proved to be an effective method of picking this up, particularly for noting different uses of language and tone when referring to civil society interactions. Language and descriptions tended to be emotive and negative but, from what I could see, unsubstantiated. This scar runs deep. How does one fix it to enable a more collaborative generation and exchange of knowledge?

The issue of a shared language ran in a similar vein to that of language use. Shared language is supposed to aid relational development to enhance knowledge transfer in a network (Carayannis et al., 2015; Gibbons et al., 1994; Nordqvist & Frishammar, 2018). The findings suggest that people in the network tended to have a similar understanding of the biorefinery concept, with biorefinery products noted as being higher value products, such as chemicals and pharmaceuticals, as opposed to firewood and charcoal. However, differentiation emerged in two main areas: depth of understanding and generic understanding. Acknowledged experts tended to have a more detailed understanding of biorefineries, while those who were either involved on the periphery or managed biorefinery-type projects tended to have a generic understanding. In some instances, the latter group expressed their concerns about not being engineers or scientists and how this might hinder their ability to express their understanding. This reiterates the skewed understanding in the network that scientific and technical codified knowledge is superior.

Another dimension of this chapter was to explore how knowledge is generated and acquired within the network. To do so, Nonaka and Takeuchi's (1995) framework was useful for classifying the types of knowledge held in the network. Examples provided by leverage professionals suggested that experiential and tacit knowledge generation are the most prominent, particularly for those who demonstrated longevity in the sector. Of interest is that the ability to make mistakes during the learning process was an important mechanism for learning. One of the main topics that emerged was the juxtaposition of experience versus formal education, and the need to find a balance between both. This was especially seen in relation to the suggested unrealistic need by industry for new entrants to have both experience and knowledge of the sector. When competency demands outstrip supply, situations can arise where students are poached by industry prior to completing their studies. This impacts academic institutions financially. However, codified knowledge was not dismissed as a valued form of knowledge acquisition, because it is important for laying a theoretical foundation for those in work. However, some did suggest that degrees need to be relevant to the workplace.

In terms of the route through which knowledge is acquired within the network, it emerged that for most, undertaking R&D, reading and contributing to written materials, and accessing information via the internet were the most prominent forms of knowledge transfer. Training, giving presentations and face-to-face interaction was by far the most prominent form of tacit knowledge transfer.

Hands-on practice and inclusion in decision-making via project work was significant regarding knowledge transfer and generating know how. This would suggest that, while the acquisition of knowledge via more formal mechanisms was valued, it was tacit knowledge acquisition that revealed itself as prominent.

The final component of this chapter explored the type of knowledge held in the network, and the South African forestry-product's biorefinery information system's ability to absorb knowledge and technologies (absorptive capacity). I did, however, become frustrated with the literature regarding absorptive capacity. Much of the literature perpetuated the notion of developing countries' reliance on and absorption of knowledge generated by advanced economies. This research suggests that, while South African leverage professionals are supportive of this approach, it would neglect South Africa's innovation policy to encourage local innovation and entrepreneurship. This led to the need for this study to explore whether we have the capacity and skills to do so. Findings suggest that we do have the capacity and skills from a technical, engineering, forestry science and managerial skills perspective. However, there is a shortage in the network of competencies associated with policy and legislative development, coordinated strategic thinking, education and training, market research, innovation finance, customer engagement and marketing of technologies and products.

I therefore argue that occupations requiring these *missing* competencies and knowledge are as important as those promoted by innovation and economic development discourse, from the perspective of having undertaken work on green economy interventions and associated systemic issues (Jenkin, 2018; Jenkin & Mudombi, 2018). These missing competencies are therefore pivotal for transitioning current R&D practices to increased uptake, something the South African forestry-products biorefinery innovation system is struggling to achieve.

On a final note, the discussion of skills and competency alluded to the transitory nature of our current skills base. Findings suggest that the forestry-products sector is struggling to meet its demand for experienced and theoretically knowledgeable new entrants due to skilled individuals leaving the sector. Accordingly, there is a need to attract and retain those who enter the sector. What emerged is a picture of a forestry-products sector that is trying to get to grips with a changing contemporary mobile workforce.

This situation is repeated the world over. I would therefore argue that, for the forestry-products sector to mitigate this, it needs to adapt to this workforce shift and create an attractive environment for the new generation of skilled individuals. If it means letting them move on to other sectors or overseas, it also means allowing them to return at a later stage with new experiences and knowledge. This is a potential way to mitigate the issue of a missing middle level of management. It could require some form of succession planning to replace individuals who are central to the country's forestry-products biorefinery innovation system.

In conclusion, this chapter contributes to existing TIS literature because it highlights the importance of understanding the nuanced types of knowledge held within a TIS. It assesses how knowledge generation and exchange occur, using a knowledge network analytical approach. Current TIS discourse is therefore further advanced by incorporating and recognising the importance of leverage professional connectivity, and the role leverage professionals play in expediating or hindering innovation uptake.

This focus on the leverage professional and the use of organisational literature to understand the knowledge dynamics in a TIS is unique. The centrality of leverage professionals as social capital is covered in the next chapter.

Chapter 9: Characteristics, knowledge, roles and behavioural preferences of leverage professionals in South Africa's forestry-products biorefinery innovation system

The purpose of this chapter is to advance the understanding and role of individuals in a TIS as agents for catalysing the uptake of biorefinery technologies and products. In the main, most innovation and economic development research exploring knowledge networks is focused at the actor (organisational) level (see, for example, Bauer et al., 2018; Bonfim et al., 2018; Huggins et al., 2012). There is little reference to individuals and their agency within the innovation system and process, or knowledge network(s). This chapter demonstrates the need to consider in more detail the role of the individual within TIS discourse and policy, thereby reinforcing the importance of social capital and the individual as "object" (Huggins et al., 2012, p. 208) within the network.

As referenced earlier, the term leverage professional has been applied to these individuals. Analysis of their interview transcripts enabled a rich interpretation of their traits, "modus operandi", role and challenges faced. This resonates with the work of Barner-Rasmussen et al. (2008) and Felin and Hesterly (2007), who recommended that better insights on the ways in which knowledge is generated and transferred between individuals in a network can be obtained by examining the individual within the system.

The purpose of this chapter is therefore to examine the individuals in the system to respond to the questions: (a) who are the key leverage professionals in the South African forestry-products biorefinery innovation system? (b) what roles do they play? and (c) what specific traits, knowledge, capabilities and behavioural preferences do they exhibit?

This chapter explores, in the first instance, the characteristics associated with the leverage professionals interviewed. The aim of this exercise was to derive a sense of who they are, and how they achieve agency, or the challenges they face in trying to do so. As a unique dimension of this study, and drawing extensively on the work of Belbin, the behavioural preferences of the leverage professionals were ascertained. This was done to determine whether the current network has an adequate combination of individuals to enhance the uptake of biorefinery technologies within the country.

This chapter also explores the core challenges that inhibit their desire to operate and act as change agents. To conclude, the profiles of three individuals are presented to illustrate some of the core characteristics associated with a leverage professional.

9.1 Leverage professional demographics

The average age of the interviewed leverage professionals was 46 years. The majority were white (71%), 20% black, 10% Asian, and 80% were male. Most females interviewed held positions in government and NGOs. This finding correlates with government statistics that suggest most women employed in the country work in "community and social services" (Statistics SA, 2018a, pg. 51). The locations of leverage professionals reflected who they worked for. For example, many are based in Gauteng because it is in this province that most national government departments, industry headquarters and trade associations offices are situated. Many were also based in KwaZulu-Natal, a province that is home to many tree plantations and hence pulp and paper operations.

The purpose of exploring age is important. It indicates whether the sector can realise its biorefinery ambitions if those in the latter stages of their careers hold the majority of the sector's expertise, knowledge and capabilities. This raises the question, do the actor organisations have adequate succession and talent retention plans to sustain the momentum of biorefinery technology and product uptake in the future? This was explored in Chapter 8 above.

9.2 Educational background and knowledge held

The majority of those interviewed have a high-level of post-graduate qualifications, notably master's or PhDs in forestry, environmental science and biorefinery technologies. However, some individuals did not conform to this. They were outliers, with either no formal tertiary education or no forestry, biorefinery or environmental associated higher education. These individuals tend to have been attracted to the biomass or biorefinery space, not through a linear educational or employment pathway, but through passion and interest. They have seen the potential for both the common good (such as job creation) and commercial opportunities biorefineries have to offer. This distinction is reflected in the work experience pathways of the professionals, which can be divided into two categories:

1. *Remainers* – those who have been embedded in the forestry and forestry-related sector for all or most of their careers (the majority)
2. *Joiners* – those who have entered the sector from other fields (the minority)

Table 16 captures the specific types of knowledge held by the leverage professionals (see Chapter 3 for the reasons for selecting the knowledge type categories). The table shows that most are involved in managerial, coordination, engineering-related or research roles so it is not surprising there is a prominence of technical, project and managerial knowledge. Technical knowledge is mainly forestry-related, with reference to biomass and biorefineries linked to this. Aside from coordination and managerial knowledge (which is predominantly tacit) the dominance of technical knowledge is not unexpected. It is similarly reflected in the overarching commentary on knowledge held beyond that of the leverage professionals within the network.

Table 16: Knowledge held by the leverage professionals, by knowledge type

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Industry					
Arianna Baldo, RSB	−Public relations	−Sustainability	−Aviation biofuels, −Plastics	−Project management −Consortium creation	−International relations −Strategy
Dr Johan de Graaf, Hans Merensky Holdings	−Biorefinery opportunities for sawmills	−New value chains R&D (forestry and agriculture) −Environmental sustainability −Horticulture plant pathology		−Research management −Forest planning −Problem-solving	−Strategy
Frans Hansen, Kimberly-Clark		−Technical management		−Project management and set-up −Due diligence	
Dr Ronald Heath, Forestry SA		−Forestry −Pests and diseases −Plant pathology −Waste beneficiation −Technical innovation −Forestry and agriculture regulations		−Research management and financing −Needs prioritisation −Cost savings	−Strategy development
Dr Arnulf Kanzler, Sappi	−Understanding of the economics	−Tree breeding and improvement (efficiencies) −Pests and diseases −Climate change impacts −Forestry ethics			

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Industry					
Dr Dirk Längin, Mondi SA	− Cost-benefit of options	− Re-engineering − Forestry and plantation whole chain − Forestry science − R&D − Technical support − Harvest technology		− Team management − Change management	− Strategy
Mike Nash, PAMSA		− Pulp and paper − Process development − Chemical engineering	− Pulp and paper	− Process development and management − Team management	
Michael Peter, Forestry SA		− Forestry − Value chain approaches − Forestry conservation and management − Indigenous forests − Standards development		− Organisation management	− Organisation management − Identification of constraints and opportunities − Strategy development − Forestry policy
Henry Reddy, LignoTech	− IP, marketing and sales	− Quality control − Environmental services	− Product optimisation	− Management − Process control − Plant manufacturing processes	− Principles
Petrus Saayman, Evergreen Timbers	− Woodchip markets − Customer relations − Sales	− Timber and sawmilling − Log procurement and production − Environmental impact assessments − Furniture making	− Timber products − Furniture	− Operational management − Target setting − Human relations − Due diligence	− Business strategy
Dr Nelson Sefara, Sappi		−Pulping and bleaching −Coating applications −Bio-composites −Scientific methodology	−Coating applications −Bio-composites −Forestry products	−General management −Protocols −Process	

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Industry					
Roy Southey, Sawmilling SA	−Market information associated with sawmilling	−Sawmilling −Biomass into energy	−Wood −Biofuels	−Skills coordination −Course material development −Strategy planning −Management −Financial	−Strategy development
Grant Trebble, independent	−Value-added industries −Financials of making it work −Understanding funding models	−Waste conversion −Link between water and alien invasive plant products −Software solutions	−Timber and restoration materials	−Programme coordination −Taking things to scale	
Jaco-Pierre van der Merwe, York Timbers	−Business case development −Business plans	−Wood technology −Nursery design		−Problem-solving	
Anthony Williams, Citius Energy	−Business development	−Chemical engineering −Biofuels and biomass −Waste to energy	−Biofuels −Renewable energy		

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Government					
Garth Barnes, DEA	− Biochar firewood and charcoal opportunities − Market information and research − Marketing − Green jobs	− Data interrogation − Applied research	− Biochar − Firewood − Charcoal	− Leverage corporate funding − Stakeholder engagement	− Advocacy
Johann Bester, DAFF	− Scientific services	− Forestry science − Plantation management − Community forestry − Forestry regulations		− Forestry operations	− Forestry policy
Sunita Kalan, DST	− Using innovation to drive national development − Patents and IP − Enterprise development and creation	− Innovation − R&D − Waste		− Creating an enabling space to support innovation − IP management − Innovation catalysation	− Bioeconomy strategy
Stephen Ngubane, IDC	− Business development − Market opportunities − Consultancy	− Forestry specialist − Forestry value chain (indigenous and commercial)		− Committee dynamics − Project and programme development and management − Project processes and structure − Interface management	− Broad-based black economic empowerment (BBBEE) − Policy and strategy
Henry Nuwarinda, NCPC		− Cleaner production − Industrial waste management − Industrial symbiosis − Air quality		− Project management − Funding applications	

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Government					
Tafadzwa Nyanzunda-Kadzombe, DTI		− Forest-based industry processing − Socio-economics Innovation			
Dr Konanani Rashamuse, DST	− Bio-entrepreneurship − Formulation of business models	− Biorefineries − Microbiology − Bioremediation − Socioeconomics		− Skills requirements − Implementation plan development − Innovation management − Thinking outside the box	− Policy making
Kira Ross, SAFCOL	− Investigating biomass opportunities − Revenue generation − Product diversification	− Feasibility assessments	− Product utilisation	− Project management − Research processes − Development of systems and databases − Production development systems − Optimisation of systems	
Christiaan Smit, SAFCOL	− Identification of opportunities	− Wood science − Biomass − Research specialist in lumber and wood − Tree breeding − Biorefineries and energy	− Wood and lumber − Product development		

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Academia and research institutions					
Prof. Linda Godfrey, CSIR and North West University	−Understanding waste opportunities	−Waste management −Waste composition −Biorefineries −Biomass and waste	−Biodegradables −Plastics	−Project implementation −Roadmap management	−Roadmap and strategy development −Understanding national policy −Strategic thinking −Advocacy
Prof. Johann Görgens, Stellenbosch University	−Bioeconomy −Rural livelihood benefit −Economic perspective −Cost dynamics −Market assessments and feasibility −Patents	−Pulp paper and sugar cane biorefineries −Technical understanding of products −Statistical modelling and scenarios	−Pulp, paper and sugar		−Biofuel strategy
Iain Kerr, UKZN and PAMSA		−Wood product carbon flows and storage −Pulp and paper technologies and production −Mill chemistry −Environmental issues and management −Water treatment −Waste legislation	−Pulp and paper	−Course management −Training −Mill management	
Prof. Theo de Koker, DUT		−Pulp and paper technologies and production	−Pulp and paper	−Course management	
Dr Andrew Morris, ICFR	−Timber product market knowledge	−Tree plantations −Pulp milling −Forestry value chain	−Timber market structure		−Company leadership

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Academia and research institutions					
Dr Jimmy Pauck, DUT		− Pulp and paper technologies and production	− Pulp and paper	− Learning management systems	
Prof. Bruce Sithole, CSIR and UKZN	− Biomass and biorefinery potential − Green economics Economic benefits	− Forestry technology − Biomass innovation − Wood chemistry − R&D − Techno-economics	− Forestry products	− Research leadership − Research centre management − Human capital development − Capability to take research to scale	
Dr Douglas Trotter, CSIR	− Understanding consumer market − Market needs	− Green economic solutions − Waste development − Resource economics − Socioeconomics − Sustainability science		− Area and team management − Manager oversight − Decision-making − Financing	− Strategic overview
Civil society					
Bhavna Deonarain, TIPS	− Sustainability and policy research − Sustainable growth − Green economy		− Sustainable biomaterials − Sustainable sourcing		
Tjaša Bole-Rentel, WWF-SA	− Conducting research − Environmental economics	− Bioenergy − Sustainability impacts	− Aviation biofuel	− Programme management and administration − Work oversight − Raising funds − Questioning and critique	
Amanda Dinan, Fetola Foundation	−Entrepreneurial needs	−Alien vegetation added value	−Aviation biofuel −Alien vegetation products		−Understanding of systemic impacts −Networking

Leverage professional	Market or entrepreneurial	Technological	Product	Process or procedural or managerial	Organisational
Academia and research institutions					
Saliem Fakir, WWF-SA	−New technology opportunities −Development and environmental economics −Innovation entrepreneurship −Circular economy		−Aviation biofuel	−Team leadership −Management −Network building and bridging −Creation of enabling environments	−Thinker and futurist −Transition theory
Jarrod Lyons, GreenCape	−Green and circular economy and investment −Return on investment and impact −Economic and business focus −Market research	−Industrial symbiosis −Alien vegetation added value −Molecular biology −Water and ocean ecology	−Alien vegetation products		
Bongani Maseko, AfricaBio		−Plant pathology and forestry diseases −Forestry value chain −Emerging technologies −Forestry and agricultural R&D			−Advocacy −Policy
Bongani Mthembu, SDCEA	−Community engagement	−Geographical information systems (GIS) −Sampling equipment use −Cradle to grave −Air and water quality −Land pollution	−Paper and plantations	−Information system development −Organisation −Presentations and speaking	−Environmental justice

Regarding the competency and capability associated with peer or colleague support, it is apparent that leverage professionals seldom operate on their own. They tend to function within, and require, an occupational network. These occupational networks are informal groupings of individuals who work with or consult each other to enable environmental and social change (Jenkin et al., 2016).

Challenges faced by several interviewees, in this regard, were the mobility and inexperience of young employees, and the loss of experienced colleagues reaching retirement age. This was exacerbated by a lack of support from decision-makers to pursue their ambitions. These challenges impacted the leverage professional's agency and ability to function effectively. These topics have been covered previously in Chapter 8, as they are also issues attributed to the overarching absorptive capacity of the forestry-products biorefinery innovation system.

9.3 Assessment of leverage professionals' roles and behavioural preferences

The majority of those interviewed held leadership, managerial, coordination and senior research positions within government, academia, industry and civil society. Many had engineering and chemistry backgrounds (such as, Prof Görgens, F Hansen, I Kerr, Dr Längin, M Nash, Dr Pauck, Dr Rashamuse, H Reddy, P Saayman, Dr Sefara, Prof Sithole, A Williams). While engineers, chemists and forestry scientists are critical leverage professional occupations, it is necessary to have a diversity of functions and individuals. These additional occupations are required to market biorefineries and products and to develop policy and strategy to support R&D and implementation (Dewit, 2018; Martinez et al., 2010; Pawar et al., 2009). This requires systems thinking to ensure biorefinery innovation is meaningful and of value. Therefore, individuals who specialise in training, market research and sales should also be considered (Dewit, 2018). In addition, the system requires individuals who will leverage change (Caldwell, 2003; Cloete, 2017; Van Poeck et al., 2017). They need to have the belief that "he or she can direct … events towards desired ends, … [and that they feel] empowered (i.e. intrinsically motivated) to engage in activity, depends on the extent to which they have a sense of: 1) Impact: 'I can make a difference'; 2) Competence: 'I am good at what I do'; 3) Meaning: 'I care about what I do'; and 4) Choice: 'I can determine what I do'" (Avelino et al., 2017, p. 4).

As became evident from discussions, the leverage professionals tended to apply their agency in two distinct ways: operating within or operating externally to their organisation. This distinction seems to be determined by whether the operational culture of their workplace allowed for or inhibited external and open collaboration, such as the need to retain IP. Alternatively, they may have lacked autonomy due to in-house protocols and hierarchical restrictions. Those who operated more externally functioned on their own or had the autonomy to work as individuals outside their organisations to realise change.

Adding to this, Swilling (2016) suggested in his work on game changers in Africa as catalysts for social and systems innovation, that change agents can also operate within mainstream dynamics, or can be more marginal. This distinction was clearly witnessed in the leverage professional interviews. Some are actively involved in or are investigating biorefinery opportunities in the forestry-products sector, while others are situated marginally in the TIS or involved indirectly, for example via alien vegetation activities. This is illustrated in Table 17.

Table 17: Leverage professionals interviewed presented by mainstream or marginal positioning within the biorefinery innovation system

Mainstream operator		Marginal operator	
Leverage professional	**Area of interest**	**Leverage professional**	**Area of interest**
Industry			
A Baldo (RSB)	Biofuel standards and potential	F. Hansen (Kimberly-Clark)	Paper product manufacture
Dr de Graaf (Hans Merensky Holdings)	Exploring biorefinery potential	Dr Heath (Forestry SA)	Commercial forestry
H Reddy (LignoTech)	Manufacture of biorefinery products	Dr Kanzler (Sappi)	Tree breeding
Dr Sefara (Sappi)	Large-scale biorefinery implementation	Dr Längin (Mondi)	Commercial forestry
G Trebble (independent)	Alien vegetation added value	M Nash (PAMSA)	Pulp and paper manufacture
A Williams (Citius Energy)	Biofuels and bioenergy from biomass	M Peter (Forestry SA)	Commercial forestry
		P Saayman (Evergreen Timbers)	Interested in biorefinery opportunities
		R Southey (Sawmilling SA)	Sawmilling
		J-P van der Merwe (York Timbers)	Exploring biorefinery potential
Government			
G Barnes (DEA)	Alien vegetation added value	J Bester (DAFF)	Forestry
S Ngubane (IDC)	Biorefinery funding	S Kalan (DST)	Supporting innovation
Dr Rashamuse (DST)	Biorefinery and bioeconomy strategy	H Nuwarinda (NCPC)	Industrial symbiosis
		T Nyanzunda-Kadzombe (DTI)	Supporting innovation
		C Smit (SAFCOL)	Forestry
		K Ross (SAFCOL)	Exploring biorefinery potential

Mainstream operator		Marginal operator	
Leverage professional	**Area of interest**	**Leverage professional**	**Area of interest**
Academia and research institutions			
Prof. de Koker (DUT)	Pulp and paper, and biorefineries	I Kerr (UKZN)	Pulp and paper
Prof. Godfrey (CSIR)	Waste and biorefinery research	Dr Morris (ICFR)	Forestry research
Prof. Görgens (Stellenbosch University)	Biorefinery research	Dr Pauck (DUT)	Pulp and paper
Prof. Sithole (CSIR and UKZN)	Biorefinery demonstration and research		
Dr Trotter (CSIR)	Biorefinery demonstration and research		
Civil society			
T Bole-Rentel (WWF-SA)	Aviation biofuel research potential	S Fakir (WWF-SA)	Sustainability policy and futures
B Deonarain (TIPS)	Biorefinery policy research	J Lyons (GreenCape)	Alien vegetation added value
A Dinan (Fetola Foundation)	Biofuel and entrepreneurial activities	B Mthembu (SDCEA)	Environmental activism
Dr Maseko (AfricaBio)	Biofuels as a biotechnology		

The distinction between working within the network or marginally presented itself as constraints that inhibited individuals' agency to function or adopt more transformative biorefinery or other interventions. The constraints are twofold: first, their capacity to operate as individuals is inhibited by internal organisational constraints; and second, external constraints, such as negative actions towards the organisation within which they work, directly or indirectly affect the way they operate. Table 18 provides a list of key constraints identified in discussion with the leverage professionals.

Table 18: Internal versus external constraints

Internal constraints	External constraints
− Siloed working and departmentalism − Narrow specialism − Competency of team members or occupational network − Organisational inertia, team spirit or lack of collectiveness − Lack of leadership support or continually changing focus − Constrained autonomy and process-heavy − Experienced colleagues reaching retirement age or lack of succession planning	− Distrust of the organisation or team or project they are collaborating with or on − Lack of recognition − Perceived duplication of efforts or misunderstanding − Lack of external funding or support − Inconsistent or dated policy − Bureaucracy or inertia and incompetence − Dominance of certain actor partnerships or collective history

The most common barriers and challenges faced were internally restrictive. The most cited were processes and protocols, misguided and changing organisation focus, and lack of colleague support and experience. External challenges included poor government and industry financial support and investment, and a lack of national unification and coordination. Internal restrictions can impact learning possibilities for the individual in the workplace (Fuller & Unwin, 2004), and therefore knowledge generation and exchange within the broader biorefinery network. This notion and some of the core challenges faced by the leverage professionals are explored further below.

Another dimension is the level of participation of the leverage professional in the forestry-products biorefinery innovation system or discourse. It emerged that only a few key individuals are actively involved in biorefinery research, discourse, policy and initiatives (18 of the 39 interviewed). Those who are directly involved have notable areas of emphasis (see Table 17). This emphasis is derived from their individual and organisational ambitions. These can be categorised as follows: (a) coordination, facilitation and management; (b) entrepreneurial and operational activities; (c) advocacy and activism; and (d) knowledge production and dissemination.

Several are involved in the coordination, facilitation and management of facilities, centres and units (see A Baldo, G Barnes, Prof. Görgens, T Nyanzunda-Kadzombe, Dr Rashamuse, Dr Sefara, Prof. Sithole, Dr Trotter). They oversee the human and financial resourcing of biorefinery-focused projects and programmes. Their functions include quality control, and programme and project management, or coordination and facilitation of knowledge networks and forums to stimulate uptake.

Individuals, mainly in civil society organisations, tend to be driven to challenge the practices in the forestry-products sector that have had a significant impact on the environment. They have a desire to support the country's transition to a green economy:

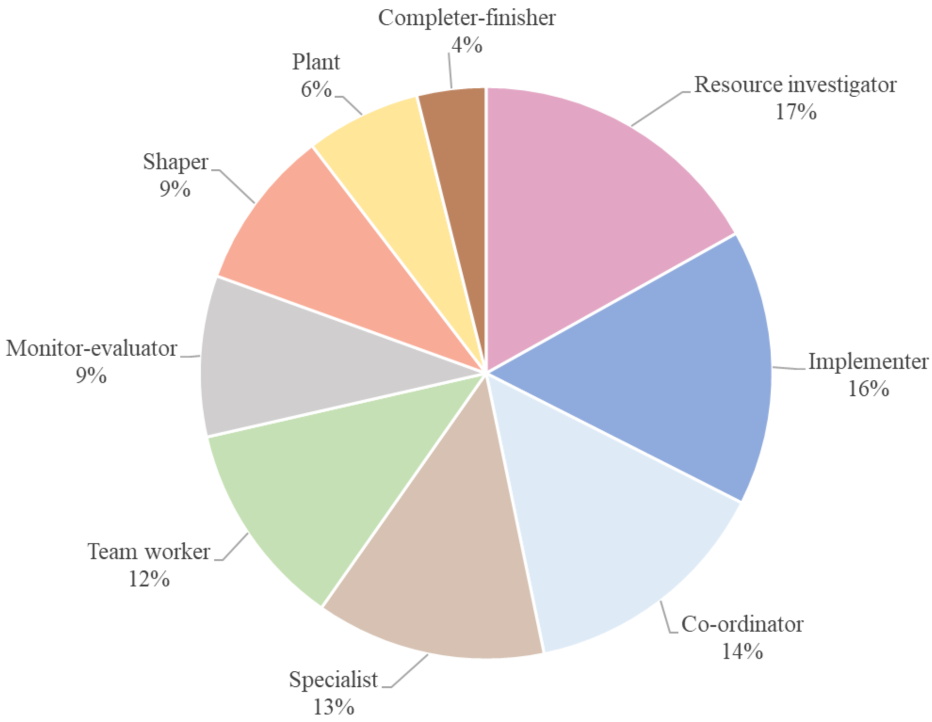
- by undertaking research and facilitating collaborative efforts and dialogues to open up biorefinery market opportunities. This is the case for those involved in WWF-SA's *Waste to Wing* project, and TIPS' biomaterials initiative
- from an activist angle, for example, individuals working for the SDCEA. Their purpose is to act as an environmental and social watch dog for communities living in the heavily industrialised South Durban basin.

9.3.1 Behavioural preferences

A core theme that emerged from the analysis was a categorisation of similar characteristics, traits and behavioural preferences portrayed by those interviewed. This warranted further exploration in terms of the potential identification and development of a set of change agent criteria. It is suggested that these criteria be used to identify current and future individuals for inclusion in an effective and collaboratively enhanced forestry-products biorefinery innovation system in South Africa. This notion is supported by the quadruple helix discourse, in which collaboration is centred around collective interaction and knowledge as a resource. Carayannis et al. (2015, p. 40) referred to this as the "circulation of knowledge" between the role players. This circulation enables innovation development within an "innovation ecosystem" (ibid., p. 37; Carayannis & Campbell, 2009; Carayannis et al., 2015; Cavallini et al., 2016b).

A subjective assessment of each interviewee, against Belbin's (2019) team role taxonomy (see Chapter 6 for a theoretical underpinning) provided an indication of the diversity of roles individuals play in the South African forestry-products biorefinery innovation system. By quantifying the two dominant behavioural preferences per leverage professional, an illustration of Belbin team role types in the system is possible (see Figure 9; see Appendix D for the definitions associated with each team role type.

Figure 9: The leverage professionals by Belbin team role type[86]



Given that the majority of those interviewed held management positions, it is not surprising that the role of *coordinator* is prominent. This is an individual recognised for their maturity, confidence, level of influence and leadership. They are also often recognised for being goal-oriented, team and project coordinators. This can be for mutual benefit or to seek collaboration. These elements are also recognised in boundary spanners and brokers (Alexander et al., 2016; Belbin, 2010, 2019; Burt, 2005; Chen et al., 2015; Ernst & Chrobot-Mason, 2011; Hsu et al., 2007; Lundberg, 2013).

The coordinator role is linked to the high-scoring *implementer* role (Belbin, 2010, 2019). This indicates that most leverage professionals are in a position that requires them to develop plans and action programmes or projects as unit or project managers. This equates to some boundary spanner characteristics, such as trustworthiness and competence to develop plans between

[86] Developed by the author.

individuals and groups (Alexander et al., 2016; Barner-Rasmussen et al., 2008; Ernst & Chrobot-Mason, 2011; Hsu et al., 2007; Lundberg, 2013; Tushman & Scanlan, 1981).

A trait common to several leverage professionals was their need to network or satisfaction in networking. This activity enabled them to garner insights to further their knowledge or to implement their ambitions. This is reflected in the fact that the role of *resource-investigator* was the most identified behavioural preference among the leverage professionals. This role is denoted by an individual with high levels of inquisitiveness, enthusiasm and adventure. They are also said to have a keenness to develop contacts (Belbin, 2010, 2019). This description echoes strongly with the literal description of individuals as brokers and boundary spanners.

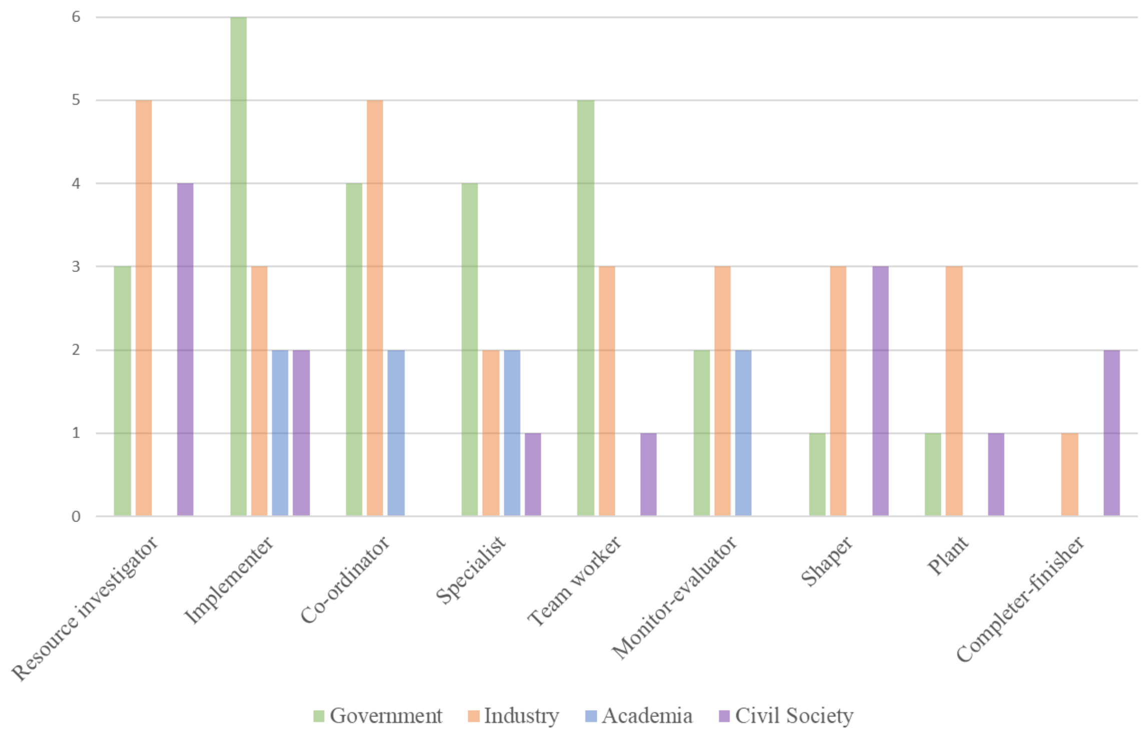
It is not surprising, given the focus in the TIS on R&D, that *specialists* were identified by others as important for knowledge acquisition and advice. This correlates with the previous chapter's acknowledgement of the central role certain individuals hold as generators and diffusers of knowledge within the network (see Prof. Görgens and Prof. Sithole as examples).

Reflecting on the change agent concept, the role of *shaper* is important. They are identified as ambitious, dynamic, and open to challenging the *status quo* to overcome challenges (Belbin, 2010, 2019). These are traits that resonate with the characteristics of positive deviants or tempered radicals within organisations (Appelbaum et al., 2007; Markova & Folger, 2012; Meyerson, 2004; Quinn & Meyerson, 2008; Seidman & McCauley, 2008; Sparks, 2005). Those identified as shapers were mainly situated in industry or civil society organisations (for example, T Bole-Rentel, A Dinan, S Fakir, J Lyons and B Mthembu). This aligns, in the main, with NGO ambitions of advocacy and activism, upon which many were established to challenge a system or issue, and to facilitate change.

A role that was not widely reflected within the network was that of *completer-finisher*. These are individuals who have a drive for perfection, completion of tasks and rigour (Belbin, 2010, 2019). This is likely because those interviewed mainly hold positions of leadership, coordination and management, as opposed to project delivery and perseverance to see a piece of work through to completion. The completer-finisher role is more likely to be observed in those holding administrative, project delivery or early- to middle-career management positions. Here, again, I refer to the knowledge network discussion on the missing middle. This is likely the result of a young, mobile workforce, and therefore a lack of individuals holding these middle management positions in the forestry-products biorefinery innovation system.

From a different perspective, Figure 10 presents the leverage professionals' Belbin team role types by actor group. It is the low columns in this figure that are of interest. They shed light on how the current TIS could transform into a more effective network of individuals to expedite biorefinery uptake. For example, no significant coordinator or specialist leverage professionals were identified in civil society organisations, with these individuals tending to sit in government, industry and academia. This implies that leadership and expertise is sought elsewhere by NGOs to provide insight and advice.

Figure 10: The leverage professionals' Belbin team role type, by actor group[87]



The *plant* role type is not well reflected across all actor groups, particularly government, academia and civil society. From a transformation perspective, plants are crucial for playing a role in catalysing idea generation, creativity and imagination, and solving difficult problems (Belbin, 2010, 2019). As change agents, they would be considered visionaries, tempered radicals and positive deviants (this is not too dissimilar to shapers). They are therefore also likely to challenge world views and behaviours (Kraft, 2017; Van Poeck et al., 2017). Where plant leverage professionals do exist, they tend to be located in industry and are involved in entrepreneurial or start-up activities, for example, G Trebble, an independent operating in the

[87] Developed by the author.

alien vegetation beneficiation space, or A Williams of Citius Energy. This is not to say that both shapers and plants do not exist elsewhere in government, academia or civil society. They do. It is, however, most likely due to organisational constraints, such as strict protocols and work culture, that individuals are prohibited from having the freedom or autonomy to deviate positively.

It should be noted that, while there are some behavioural preference gaps, there is an adequate mix of roles operating in the South African forestry-products biorefinery innovation system. This suggests that, from a leverage professional perspective, the TIS is adequately resourced with individuals (or absorptive capacity). It is their connectivity that is constraining their potential to collaborate more effectively as a unified network of individuals.

9.4 Examples of three leverage professionals in the forestry-products biorefinery innovation system

This section provides details of three individuals who represent the core characteristics required of a leverage professional operating within the South African forestry-products biorefinery innovation system. The selected examples demonstrate how, through their agency, they aim to leverage change and escalate the adoption of biorefinery and associated activities in South Africa.

The three individuals selected are Prof. Bruce Sithole of the CSIR, Jarrod Lyons of GreenCape and Dr Nelson Sefara of Sappi. For each, a brief profile is presented on their age, job title, role, education and employment history. This is followed by a commentary on how they operate to expedite uptake and overcome challenges to leverage change. The ability to overcome challenges is a core consideration for individuals who represent change agents. According to Pascale and Sternin (2005, para. 18) these individuals are identified as “exceptions to the norm, people in identical circumstances [to their colleagues] who seem to be coping especially well”.

Example 1: Prof. Bruce Sithole

Age*:* 60

Job title 1*:* Chief Scientist, Principal Researcher and Director of the Biorefinery Industry Development Facility

Organisation 1*:* Council for Scientific and Industrial Research (CSIR)

Job title 2*:* Professor of Chemical Engineering

Organisation 2*:* Department of Chemical Engineering, UKZN

Quadruple helix actor group*:* Academia and research institutions

As can be observed from the above, Prof. Sithole holds a number of job titles, which illustrates the link between his work as a Chief Scientist at the CSIR and that of his academic role through a joint venture with the UKZN. Interestingly, the CSIR Facility he runs is located next to the Department of Chemical Engineering at UKZN. This enables easy boundary spanning between the two roles and places, such as acting as a supervisor to UKZN post-graduate students who are based at the Facility undertaking biorefinery research.

Through the interviews with other leverage professionals within the TIS, Prof. Sithole emerged as a significant member of the system, notably for his expertise and knowledge of forestry-product biorefinery products and technologies. His main mechanisms for acquiring knowledge are talking to or visiting industry members, undertaking techno-economic studies to understand biorefinery opportunities in the country, and trialling biorefinery innovations for industry in the CSIR laboratory. Prof. Sithole also draws heavily on his educational and occupational experience and learning, which are characterised by international study and work experience, from undertaking his MSc in Aberdeen, Scotland, and working for the Pulp and Paper Research Institute in Canada. It is from the latter that Prof. Sithole was headhunted to return to South Africa to catalyse the Biorefinery Industry Development Facility for the CSIR in South Africa. This was at a time when funding was being withdrawn for public research from major pulp and paper mills in the country due to a declining market for pulp and paper. Upon his return to the country in 2010, he took up a position as the head of the Forestry and Forestry Products

Research Centre – a joint venture by the CSIR and UKZN to explore how the pulp and paper sector in South Africa could be helped to survive. It was through these explorations that poor tree yields, and associated waste material were identified as an opportunity, and biorefineries as the potential solution to extract value.

When speaking to Prof. Sithole, it is clear he is passionate about the opportunities biorefineries can offer the forestry-products sector, and others, such as agriculture. He comes alive as he shows you around the CSIR's biorefinery facility, speaking knowledgably about the forestry sector and showing the equipment and biorefinery products. His mechanism for disseminating knowledge is infectious, with many of those interviewed pointing to how Prof. Sithole had inspired them to explore biorefinery opportunities in their operations, such as SAFCOL, Hans Merensky and Evergreen Timbers. Most leverage professionals know of him too. In referencing the Belbin team role taxonomy, these traits clearly align Prof. Sithole with the role of specialist – an individual who "brings in-depth knowledge of a key area to the team" (Belbin, 2019, box 6). They are often "single minded, self-starting and dedicated", and "provide specialist knowledge and skills" (ibid., box 6).

While Prof. Sithole exhibited many characteristics suitable for a leverage professional – having peer respect, being passionate, inquisitive, committed, well networked, educated and experienced – he also had challenges that inhibited the full potential of his agency. These were bureaucratic internal procedures, the cost of services offered by the CSIR, reliance on government funding to operate, cost of IP (protection) and time. Regarding time, he noted that academia takes five to ten years to develop a technology, and industry wants it now.

In conclusion, what struck me about Prof. Sithole was his ability to persevere by drawing on his passion, applied knowledge, networks and experience to bring about change. When asked, "what do you think you've got that has enabled you to make this change happen?" he responded: "I think I'm very inquisitive about this, … because I remember even when I was young at primary school [in Zimbabwe], I was very inquisitive about everything. … my grandmother called me a little scientist."

Sources: Prof. Sithole, Interview 26, August 9, 2017 and Interview 27, August 1, 2018.

Example 2: Dr Nelson Sefara

Age*:* 48

Job title*:* General Manager, Sappi Technology Centre

Organisation*:* Sappi

Quadruple helix actor group*:* Industry

Dr Sefara heads up one of Sappi's three international technology centres. The centre he oversees is based in Pretoria, with an associated unit operating at their Saiccor Mill in Durban, KwaZulu-Natal. He explained the Centre undertakes biorefinery R&D, for which the application and testing is undertaken at Saiccor. The Centre's role is to act as Sappi's international Centre of Excellence for pulping, bleaching and stock operations, including bio-composites.

From the outset of our interview, Dr Sefara exhibited commercial industry traits, often talking from the perspective of Sappi as opposed to that of himself as an individual. His focus is to ensure Sappi maintains its competitive advantage in the global pulp and paper sector. He illustrated the traits of Belbin's resource-investigator and coordinator roles. The former uses his "inquisitive nature to find ideas to bring back to the team … and explore opportunities", with the need to "focus on the team's objectives" (Belbin, 2019, box 1). The latter is reflected in his role of managing the activities of the Centre and ensuring it meets and delivers the R&D objectives "we promised we would achieve for the year", and Sappi's ambitions to realise more than US$1 000 million in new business, "about 75% of that should be from biorefineries." He came across as focused, determined, committed and serious about achieving this vision. He spoke confidently about where biorefinery investment should focus – in the southern hemisphere, where trees grow fast, which makes the supply of feedstock cost-effective. This focus, commitment and drive aligns with the descriptions of tempered radicals –who hold onto goals to push through and accomplish tasks (Meyerson, 2001, 2004; Sparks, 2005), and positive deviants, who bring passion, positivity and commitment to their work, and generally operate at a higher level of intensity than their peers (Markova & Folger, 2012; Pascale et al., 2011; Seidman & McCauley, 2008). He also questioned small-scale operations and projects such as

Waste to Wing, which, while interesting, he felt would be costly. Consequently, he felt aviation fuel was not a viable avenue for Sappi to pursue. This openness to challenge and critique represents the characteristics of Belbin's shaper role, whose strengths are identified as "challenging, dynamic, [and] thrives on pressure" (Belbin, 2019, box 7).

Dr Sefara presented many suitable characteristics of a leverage professional – committed, knowledgeable (applied technical, economic, market), explorative, experienced, and with a desire to make biorefineries commercially viable. While Dr Sefara exhibits many of the traits of a leverage professional, he does find himself in a compromising situation with regards to contributing to the TIS to expedite biorefinery uptake. While he is clearly a supporter of biorefinery technologies, this is mainly for the benefit of Sappi, and as such he questions the desire to collaborate more openly within the innovation system. However, he did note that he [and Sappi] do contribute to biorefinery and forestry-product discourse and offer student placements, but at a pre-competitive stage. In addition, Dr Sefara also noted internal challenges which sometimes impacted on Sappi's inability to operate effectively, such as delays at mills due to a lack of 35 to 50-year olds skilled in running maintenance projects. He attributed this missing middle to "people I lost to Indonesian companies … Canada too … [due to] the current political situation, which has made a lot of them unsettled." This is a clear example of brain drain from the sector and country).

In conclusion, Dr Sefara presented himself as someone who has a job to do and is proactive about ensuring Sappi stays at the forefront globally, with biorefineries identified as a crucial target for doing so. He is driven and committed to achieving this target. This is done in a stable, large-corporate, well-funded and internationally supported environment. When asked "what characteristics or attitude do you think you bring to this innovation system, … why do you think you are where you are?" he replied, "… it's a fascination with wanting to see new things happening … coupled with … telling people I don't resist change. If you told me to get to work, then I'm there. Change fascinates me. It brings new things to explore, so I'm fond of this. To me it's about moving out of your comfort zone, that's what drives me. Being able to explore things that look unachievable or unattainable. That excites me."

Source: Dr Sefara, Interview 19, September 3, 2018.

Example 3: Jarrod Lyons

Age*:* 36

Job title*:* Liaison: Green Economy Investment and Finance

Organisation*:* GreenCape and Wesgro

Quadruple helix actor group*:* Civil society

Jarrod (using his first name feels more appropriate due to his youthful demeanour), holds a liaison function between GreenCape and Wesgro. As he noted, "I'm a shared resource."

One of the first impressions I had when interviewing Jarrod was of his infectious enthusiasm and energy. He loves what he does and is passionate about helping people understand the added value of waste. He entered this area of interest while working at GreenCape and, through exploring the wood sector, he realised its potential and proposed it should be an area that the organisation explored further. As such, he "dived a lot deeper into that space". It was also through his brother-in-law (who works for the Western Cape Province's government) that discussions initiated the exploration of how to make alien vegetation clearing a viable option, and "focused my attention there while I was in the industrial symbiosis team." It is this focus on commercial viability and return on investment that appears to have garnered much interest. It was initially an unfunded piece of work in GreenCape, but his colleagues realised he was meeting people and gaining insight, and it was not affecting his job, so they placed him in the liaison position he currently holds. It requires him to promote investment in the broader green economy – by doing so, he draws on the insights and research produced by his colleagues in GreenCape and "feeds these insights into an organisation like Wesgro, … who will use me to try and sell the Western Cape and Cape Town as a green economy investment destination." This explanation aligns comfortably with the description of a broker and boundary spanner, people who connect two or more groups, mediate interactions, enable communication between actors, and facilitate the flow of resources (Alexander et al., 2016; Ansett, 2005; Chen et al., 2015; Ernst & Chrobot-Mason, 2011; Safford et al., 2017). Burt (2005) noted that brokers are rewarded for their ability to integrate by faster promotion and higher compensation than their colleagues. This is represented in Jarrod's profile. His action of working outside his formal job description aligns with the concept of a tempered radical, someone who operates on the edge and perseveres by chipping away at challenges to create small wins and change (Meyerson, 2001, 2004; Sparks, 2005).

Jarrod plays a crucial role as a knowledge generator and diffusor within the TIS to enable business development through engagement with both the international and the national business sector. His main mechanisms for generating and diffusing knowledge are undertaking or drawing on research to produce documents and reports to promote investment and provide insight. He also connects directly through his network, international and national trips, speaking to people to disseminate findings and market intelligence. This is reinforced by his broad knowledge and experience of topics such as the green economy, economics, alien vegetation, industrial symbiosis and ecology.

While Jarrod presents as someone who is focused, ambitious, proactive, an investigator, knowledgeable and passionate (all traits required of a leverage professional), he does face challenges that inhibit his agency, most notably senior level government officials and their lack of understanding of the value GreenCape can bring to enable the economy. This point responds to an earlier observation that, while civil society organisations such as GreenCape are connected into the South African forestry-products biorefinery innovation system, they are not adequately used as a source of information to inform the innovation process. He also noted that one of the other main challenges was a lack of understanding of the significance of waste and how to add value to it ("they think they know"). To mitigate this, he suggested there was a need to improve understanding of how to commercialise this value add, such as by biorefineries "and that we need someone to market Bruce's [Prof. Sithole's] outputs … he is not a schmoozer." This latter point speaks to the marketing and market research knowledge gap in the South African forestry-products biorefinery innovation system.

When Jarrod elaborated on how he works, he explained it was, "as a schmoozer, and a little bit of a hustler. My insights are one or two lines long and they are applicable to what I know is the lever that gets the market going." He indicated, "I like to drive what she [a work colleague] has found into the industry."

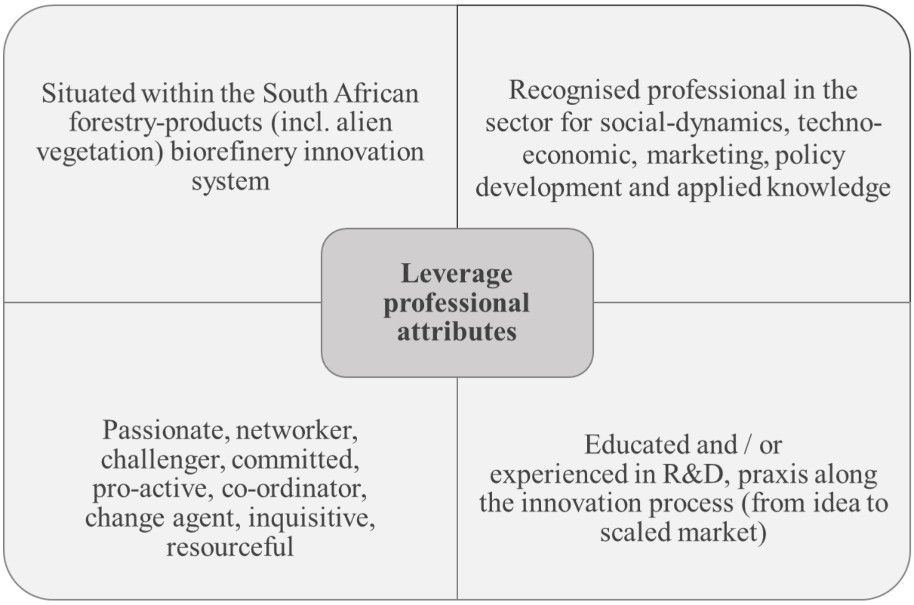
Source: J Lyons, Interview 37, October 19, 2018.

These three examples illustrate the requisite traits of a leverage professional and how they lever their agency. All three are brokers or boundary spanners. This is shown by their either linking academia with applied research, internal corporate teams with research centres, or liaising between civil society and industry. They draw on their specialist or generalist applied expertise and knowledge to seek opportunities and proactively try to realise them. They are driven by their passion and enthusiasm to do so. All of them showed inquisitiveness and a fascination for exploring solutions and how these could realise commercial benefit for the sector or the country. They are all well networked, and it is through this network that they generate and acquire knowledge. They do so by relying on a team to generate knowledge and insights to make decisions or to catalyse biorefinery or green economy opportunities. Their *modus operandi* is action-based and active; they talk, they visit, and they research to inform what they and those in their network wish to achieve.

9.5 Conclusion

The aim of this chapter has been to acknowledge and understand the role of the individual as change agents in the South African forestry-products biorefinery innovation system. This study therefore contributes to TIS literature by illustrating and uncovering several important attributes and dimensions that leverage professionals contribute to TIS'. Drawing on the findings and examples, a set of the attributes required by a leverage professional in a forestry-products biorefinery innovation system is proposed in Figure 11.

Figure 11: Proposed attributes of a leverage professional within an effective South African forestry-products biorefinery innovation system[88]



In addition, the chapter contributes to TIS literature by providing a more in-depth classification of individuals. This provides a framework for assessing the leverage professional characteristics required to transition a TIS from a formative to a mature phase. This includes transitioning from a predominant focus on R&D to scaling up implementation and acceptance of biorefinery technologies and products in the country.

The findings lay the foundations for better understanding the current roles individuals are playing, which currently focus on engineering solutions. This is evident from the predominance of engineers in the TIS and its associated knowledge network. It is therefore argued that, for the system to reach its full potential (improved uptake of biorefinery technologies and products), more leverage professionals with different occupations and roles are required, such as policy developers, social researchers and marketeers. This could be achieved through the inclusion of more plants (creative, idea generators) and shapers (challengers), mainly into government and academia, to recognise and challenge the *status quo* to expedite transformation.

For the South African biorefinery innovation system to transition to scaled implementation, it needs to recognise leverage professionals in two significant ways: first, a diversity of leverage professionals is required in the innovation process, from R&D through demonstration to market

[88] Derived by the author

research and then to commercial implementation; second, it needs to recognise a diversity of roles, from those who can develop cohesive policy to those who can generate and challenge ideas, and then onto those who can implement them.

From the perspective of leverage professionals, the importance of a network, whether internal or external, is critical for exchanging knowledge, both to advance their own ambitions, and to act together in a collaborative manner to achieve improved uptake. This will require from them the development of new or improved (and initially challenging) relationships and partnerships with civil society, so that innovations are mutually beneficial. It is in these situations that the role of resource-investigator or boundary spanner become important.

For leverage professionals in government, a more considered assessment of their role as enablers is required, in particular of their role in ensuring policy and financial support that recognises efforts in other national departments. They also need strategies that are cohesive, coherent, directional and enabling for industry, academia and civil society. This specifically refers to the need for alignment of well-informed, evidence-based government policy.

To ensure a viable future for biorefinery technologies and products in South Africa, it will also be important to recognise the need for succession and skills planning. Roadmaps, strategies and policy should acknowledge the need to offer entry-level employees the opportunity to enhance their level of experience in this field. They should also assess how best to attract a demographically diverse youth into the sector. While they may venture out of the country or into other sectors, they should be encouraged to return to the sector. This will ensure the replacement of senior leverage professionals when they retire, thereby sustaining and building on innovation and improved efforts.

Chapter 10:
Conclusions and reflections

This chapter provides an overview of the main arguments and conclusions of the thesis. I discuss some of the implications of the study's findings for innovation and economic development research and discourse. Thereafter, I consider the limitations of the study and future possible research. The chapter ends with a comment and reflections on how this study has contributed to TIS knowledge.

10.1 Summary of analysis

This thesis aimed to explore and understand the current biorefinery innovation landscape associated with the forestry-products sector in South Africa, and how collaborative it is. It was also interested in understanding how knowledge is generated, acquired and diffused in the knowledge network associated with the TIS. The exploration of how individuals apply their knowledge and agency to catalyse increased uptake of biorefineries within the system is uncommon in TIS studies.

The study posed the questions: (a) how collaborative is South Africa's forestry-products biorefinery innovation system? (b) what are the dynamics of the knowledge network associated with South Africa's forestry-products biorefinery innovation system? and (c) who are the key leverage professionals in the forestry-products biorefinery innovation system?

The thesis adopted a meta-theoretical focus, using TIS as the overarching theoretical framework, to which all other components were linked theoretically and analytically. This approach was adopted to ensure a unified thread of thought, discourse and analysis throughout. My study adopted a mixed methods approach. Applicable approaches were used depending on the question being asked. All approaches were justified as relevant for informing and understanding the dynamics of the innovation system.

To ascertain the status of the current forestry-products biorefinery innovation system, and its level of collaboration, I adopted two core system of innovation variants: first, the TIS framework to analyse the functional dynamics of the system; and second, the quadruple helix model to assess the collaboration. This model acknowledges civil society as a key role player alongside government, industry and academia. In answering Question (a), I found that the study demonstrates that the South African forestry-products biorefinery innovation system is not as collaborative as it could be. Civil society is the most notably marginalised (the South Durban community tended to be unrecognised or disregarded as equitable partners within the innovation process). Civil society may be active in the system, but its members are not being widely integrated or acknowledged as generators of knowledge or as equitable partners in the system. In addition, the system is comprised of a set of intra-connected smaller networks of actors and individuals, as opposed to a single unified collaborative network. Finally, the findings suggest that the TIS sits between a formative and a mature life cycle stage. This is mainly due to a predominance of research and development activity, and little diversity in further commercial application – with Sappi dominating this area.

To arrive at an answer to Question (b), about the dynamics and nature of knowledge in the forestry-products biorefinery innovation's systems associated knowledge network, it was important to recognise the centrality of knowledge and learning within broader systems of innovation and TIS discourse. This stimulated some of my initial thinking around the connectedness of individuals in the knowledge creation process. As the TIS framework for assessing knowledge generation and exchange proved limiting, I moved on from the more commonly used social network analysis approach to knowledge network analysis, in combination with the concept of social capital. This combined approach was used to explore the structural, relational and cognitive dimensions of the TIS. The Gephi analytical tool proved particularly useful for mapping the structural dimensions.

The findings confirm that a network plays an important role in knowledge exchange. However, it emerged that the South African forestry-products biorefinery innovation system knowledge network is dominated by industry, academic and government actors who hold key positions of centrality. These actors and individuals determine knowledge generation and diffusion. The strength of the industry-academia relationship shows up in the type of knowledge identified, which tends to be techno-economic. In addition, intra-networks were identified, which have resulted in siloed knowledge networks around certain areas of activity, such as alien vegetation and NGO advocacy and research.

Trust emerged as a significant knowledge exchange variable, thereby confirming the findings of social capital and learning literature. Trust and a history of knowing impacted the exchanged knowledge in three key ways: first, reaching out to an *alma mater* as a key source for codified knowledge; second, holding onto or locking-in knowledge that might enhance competitive advantage; and third, hindering the recognition and use of knowledge held by civil society in the innovation process.

Finally, in response to the innovation and economic development literature's assessment of absorptive capacity and the ability of those within it to adapt and adopt innovations, the findings suggest that the system is rich in managerial, technical, engineering and techno-economic research capacity. However, two absorptive capacity constraints require attention. The first constraint could be overcome by discovering how to cope with a mobile millennial workforce and ensure adequate succession planning is put in place. This should mitigate a management missing middle and therefore prepare for future leadership and agency. The second constraint could be overcome by ensuring a diversity of capabilities and skills is available in the system to generate ideas, challenge proposed strategies, and ensure that activities and projects are completed.

My research study had a specific interest in the role leverage professionals play in the South African forestry-products biorefinery innovation system and its associated knowledge network. As this is an area little covered by TIS research, I drew on behavioural and organisational frameworks to provide this understanding. As such, I undertook a mapping exercise to assess the centrality of the leverage professionals within the network. I found, in answer to the research Question (c), about the role of leverage professionals, that it was notably apparent that four individuals play a significant role of agency within the system. These are two academics who specialise in biorefinery R&D - an individual involved in the development of bioeconomy and biorefinery policy, and the lead of Sappi's biorefinery programme. Other leverage professionals play a more subsidiary role. For example, government professionals tend to facilitate discourse. Those in civil society play the role of advocate or facilitate dialogue. Most in industry, aside from Sappi and LignoTech, have adopted a wait-and-see and questioning role. The findings suggest that leverage professionals portray or require particular traits to fulfil and enhance their agency. The application of behavioural preferencing approaches, such as Belbin's team role taxonomy, can assist with determining the most effective grouping of individuals to operate in or coordinate an effective South African forestry-products biorefinery innovation system, especially given that the current leverage professionals have a leaning towards specialist, research and coordination roles. This needs to be broadened to represent a diversity of roles, knowledge and experience along the forestry-products value chain. The characteristics of the individual directly determine the dynamics and dimensions of the TIS' associated knowledge network, and therefore its level of collaboration. This was indicated by Belbin (2019, para. 1), “a team [aka network] is not a bunch of people with job titles, but a congregation of individuals, each of whom has a role which is understood by other members.”

10.2 Research implications

From the perspective of collaboration, this study offers a view that the inclusion of civil society in the innovation process is critical. This is particularly the case for TIS research in developing economies, most notably South Africa, where the historical past disregarded the voice of non-white society. The work of Botha et al. (2016); Douglas (2019) and Schillo and Robinson (2017) helped to frame this element of the study.

My work contributes to the TIS’s analytical framework, as I argue it provides an approach for examining in detail, the dimensions and flows of knowledge within an associated TIS’ knowledge network. It also offers an approach for determining the types of codified and tacit knowledge held within the TIS.

Most significantly, the study contributes to TIS discourse by building on the limited research on the role of individuals as agency within a TIS. It provides a mechanism for identifying the central role players within the network and mapping the flows of knowledge within it. It also aids in determining the roles, traits and behavioural preferences of those currently operating in the system. This provides the mechanisms to ascertain gaps, and how these might be filled to enhance the effectiveness of an innovation process to transition to a more mature phase.

These findings could be of interest to innovation and economic development, TIS, education and labour, and to business and organisational scholars, because it reflects the multi-disciplinarity of the research, and links knowledge and organisation theory and frameworks with innovation and economic development discourse. It also illustrates the importance of understanding the innovation process at the level of the individual, and how these individuals can enhance the effectiveness of an innovation system.

The insights and tools generated in the study are of interest. They provide a mechanism for linking and integrating the theory and methods to understand three levels of a TIS: first, the overarching status and structure of the system; second, how knowledge is generated and diffused between actors and individuals within the system; and finally, drilling down to the level of individual agency.

10.3 Limitations of the thesis

It is important to reflect critically on the theoretical framework and tools drawn on and developed to undertake the analysis of data for this study. Some of the key limitations of the research are highlighted below.

The most significant limitation of this study was the emphasis placed on the interview transcripts as a central source of data. This could be deemed to affect the validity or generalisation of the research. However, what I did learn from this process is that, if a key individual within the TIS is consulted from the onset, a core set of individuals can be identified for interview. In addition, through interviewing the initial set of identified individuals and use of my knowledge about the sector, a broader net could be cast, and additional individuals identified.

To assess whether an adequate number of individuals had been interviewed, an indicator of circularity was applied. This refers to the repetition of certain names and contacts in interviews, thereby ensuring that, while not everyone within the TIS could be reached, a suitable representation of individuals was covered. One of the outcomes of this approach is the finding that, through the assessment of centrality, key contacts emerged as central nodes for knowledge generation and diffusion.

A second significant limitation may be the use of Belbin's behavioural preferencing framework, which has been deemed theoretically weak or popularist. I was very aware of this. However, it was one of the few frameworks that provided a tool for understanding the role of the leverage professionals in the network, and thus to improve its effectiveness, so I decided to use it. To mitigate the consequence of applying this framework, I identified a few academic sources (such as Aritzeta et al., 2007; Flores-Parra et al., 2018; Genc, 2017; Prichard & Stanton, 1999) that referred to or adopted the approach. This enabled me to validate its use. However, its application within TIS research appears uncharted, and therefore open to scrutiny and improvement. In relation to the adoption of the Belbin framework, it should also be noted that in praxis (whether for academic study or organisational reflection), two key points need to be considered: first, individuals are normally asked to complete a series of questions from which their behavioural preferences are determined; second, most individuals play two to three of the roles. This role playing can change over time and is dependent on experience and position. I did not ask the interviewees to complete a series of questions for two reasons: first, the usefulness of Belbin's taxonomy only became apparent after the interviews had been undertaken; and second, it was felt that, as behavioural preferencing was only one of several elements in this study, doing so would not add any insight to the findings. Accordingly, I assessed each leverage professional against the role criteria by analysing the verbatim discourse captured in interview transcripts and through participant observation during interviews. I recognise the subjectivity in doing so. Although this approach may be deemed academically inadequate, this would only be true if the focus of this study were solely on the leverage professionals.

A final limitation acknowledged is the noticeable gap or neglect of market demand for biorefinery products in South Africa. Given the difficulty in obtaining information on market demand, and acknowledgment from respondents that little market research exists on biorefinery products in the country, it is suggested that emphasis should be placed on undertaking in-depth market research This should include market potential, type and suitability of biorefinery products and consumer acceptance. This research should build on the extensive techno-economic research undertaken to date.

10.4 Reflections

The aim of this study was to gain a better understanding of the status of South Africa's forestry-products biorefinery innovation system; and to explore whether it has the capability or the capacity to upscale biorefineries in a more collaborative way. By so doing, I developed a framework to explore the linkages between the overarching forestry-products biorefinery innovation system, its associated knowledge network, and leverage professional agency within it. This was achieved using TIS as the overarching framework to ensure that a cohesive thread ran through the study. Yet, I was able to draw on other, predominantly organisational and behavioural, literature to understand the dynamics of the associated knowledge network and to shine a light on the individual. I therefore propose that this approach and lens provides a mechanism for building on and strengthening TIS discourse. It enables a better understanding of the types of knowledge, mechanisms of knowledge generation and diffusion, and types of individuals required to expedite biorefinery uptake. This is a unique strength of this study. As such, I hope my analysis and findings will convince others of the need to recognise the individual in TIS discourse, especially in a country such as South Africa where good policy exists, but implementation and coordination are poor. It is through this study that I strongly propose that it is down to the willpower of the individual to overcome barriers to escalate the uptake of biorefineries. Ultimately, all actors interested in biorefineries as a sustainability solution desire to achieve the same thing, even if the reasons or mechanisms may differ, such as financial or social.

This study has shown me that we do have the absorptive capacity and passion within the country to adopt biorefinery technologies. However, we need to provide the stimulation and platform to attract and retain individuals of varying skill levels and behavioural preferences. We also need to provide a trusting space in which a diversity of knowledge can be considered, respected, critiqued and tested. Finally, a supportive financial and social environment should be provided to encourage connectivity to expedite the innovation process, while allowing the flexibility and space for intra-networks to specialise.

Although this study did not set out to inform South African bio or green economy, or biorefinery or NIS policy, I feel it is worth reflecting on this element. This is because, while South African policy is not always adequately implemented, it is considered a fundamental lever for catalysing action and change. What has emerged from this study in this regard is that South African policy on biorefineries and related issues is disconnected and, in some instances, dated. Hopefully, the establishment of entities like the National Biorefinery Platform by the DST will stimulate the development of a more cohesive policy. However, a word of caution should be heeded about who informs and is included in policy development to regulate and incentivise action. This study clearly indicates that civil society is not adequately included in policy development, even though they undertake research and facilitate dialogue in this space. It is therefore suggested that civil society organisations should be better informed of and engaged in policy development. Thus, biorefinery activities would be more aligned, would build on work already undertaken and therefore, hopefully, be received in a more positive and receptive manner. Where feasible, learning from those involved in the successful commercialisation of biorefinery innovations (predominantly industry) should be engaged more openly. This would help to improve the understanding of how to use biorefineries to add value to the forestry-products sector's waste streams. In the case of customers, it would help them to understand the benefits of biorefinery products and thereby stimulate growth in the market.

The above considerations allude to the individuals who could be consulted in this regard or brought in to catalyse uptake. In this case, this study clearly illustrates two thoughts: first, that the innovation process requires more than the knowledge, experience and skills of engineers and scientists. It should also recognise the importance of those with knowledge and skills in developing policy, undertaking market research, formulating marketing strategies, and implementing commercialisation. The second thought is that engagement with individuals who have a position of centrality within the system to formulate and revise policy and strategies to overcome barriers for implementation should be prioritised. This sentiment is adequately captured in South Africa's *National development plan* as follows*:*

> "South Africa's competitiveness will rely on national systems of innovation permeating the culture of business and society. Innovation and learning must become integral. That will require interventions from the schooling system through to shop-floor behaviour to research and development spending and commercialisation." (National Planning Commission, 2011, p. 131)

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Appendix A
Semi-structured interview guidance questions

1. Professional role

   1.1 Please confirm your age/gender?

   1.2 Occupational profile:

      1.2.1 What is your job title and function?

      1.2.2 How many years have you been employed in this function?

2. Biorefinery technologies within the forestry and pulp and paper sector in South Africa

   2.1 What is your understanding of biorefineries/biorefinery technologies/products?

   2.2 How – if at all – are you/your organisation involved in either R&D or implementation of biorefinery technologies?

   2.3 In terms of your understanding, what is the status of biorefinery technologies in South Africa (and in relation to international activities)?

   2.4 From your perspective:

      2.4.1 What are some of the challenges facing the introduction and scaled uptake of biorefinery technologies in South Africa (and the forestry/pulp and paper sector)?

      2.4.2 From your perspective, what do you think some of the key opportunities are for introducing biorefinery technologies in South Africa (and the forestry/pulp and paper sector)?

      2.4.3 What needs to happen within South Africa to catalyse or improve the uptake of biorefinery technologies within the forestry/pulp and paper sector? Mechanisms, approaches, and so on.

   2.5 What have been some of the major changes (technical, production, management, policy, etc.) in biorefinery technology research, development and implementation (as a manager, engineer, technician, etc.)?

      2.5.1 What has the effect been of these changes on the content of your jobs, skills required, or types of knowledge (formal and on-the-job) required?

3. Your professional role in relation to biorefinery technologies within your organisation

   3.1 What is your employment journey (first job through to current)?

3.2 Educational pathway/journey:

3.2.1 What education and training do you have? Where did you study? Reason for choice of study/training?

3.2.2 Has your educational background and previous work experience prepared you sufficiently for (explain reasons)?

3.2.2.1 *Network activities*: Negotiation, facilitation, coordination, management?

3.2.2.2 *Biorefinery innovation*: Technical, research?

3.3 Are you a member of a professional body? Name?

3.4 Does your organisation recognise your role in biorefinery innovation? How autonomous are you?

3.5 What recognition are you given by other professionals in the biorefinery innovation system?

3.6 Which job functions in your organisation do you work or consult with to research, develop or implement (biorefinery) innovations?

4. Your professional role and scope of practice within the national biorefinery innovation system

4.1 What role do you play in the wider South African pulp and paper/biorefinery innovation system?

4.2 What characteristics, attitudes and practices do you think you have/adopt that have enabled you to become involved and make things happen in the biorefinery system in South Africa (for example, experience, knowledge, connections, education, personality, leadership)?

4.3 What other organisations, academic institutions, government departments or NGOs do you work or collaborate with to research, develop or implement (biorefinery) innovations?

4.4 Who, or which job functions, in these other organisations, are most open to collaboration?

4.5 What is the locality of the organisations, institutions and individuals you collaborate with, for example, local, regional, national or international?

4.6 What are the benefits of being involved in a wider network?

5. Knowledge acquisition, production and diffusion

5.1 How do you keep abreast of changes and updates in (biorefinery) innovation?

5.2 How do you share or communicate knowledge and information within the (biorefinery) innovation network?

5.3 How do you/the network identify areas of (biorefinery) innovation focus; for example, collaborate on roadmaps and strategies, signatories to initiatives, government policy and incentives?

5.4 What are some of the barriers that hinder your ability to access and share information within your organisation and the sector?

6. Occupations, skills and capabilities

6.1 What jobs, skills and capabilities do you think are needed to coordinate, support, carry out research, develop and implement biorefinery technologies?

6.2 Do you think South Africa has the skills and capabilities to increase the uptake of biorefinery technologies in the pulp and paper sector?

6.3 Do you believe the education and training of professionals in biorefinery technologies is adequate in this country?

7. Are there any other matters in terms of this issue that you would like to mention?

Closing remarks

Thank you for your time and insights. The findings will be used as part of my research thesis and related academic publications. I would appreciate being able to contact you in case further information is required. Thank you once again.

Appendix B
List of leverage professionals interviewed

Interview ID	Name	Organisation	Job title	Interview date
Government (including government delivery bodies and state-owned entities)				
1	Garth Barnes	Department of Environmental Affairs (DEA)[89]	Deputy Director: Advocacy and Risk Management	October 8 & 18, 2018
2	Johann Bester	Department of Agriculture, Forestry and Fisheries (DAFF)[90]	Deputy Director: Technical and Information Services	August 10, 2018
3	Sunita Kalan	Department of Science and Technology (DST)	Director: Sector and Local Innovation	September 5, 2018
4	Steven Ngubane	Industrial Development Corporation (IDC)	Senior Project Manager: Agro-Processing and Agriculture	August 2, 2018
5	Henry Nuwarinda	National Cleaner Production Centre South Africa (NCPC-SA)	Project Manager	October 16, 2018
6	Tafadzwa Nyanzunda-Kadzombe	Department of Trade and Industry (DTI)	Director: Resource-Based Industries	September 25, 2018
7	Dr Konanani Rashamuse	Department of Science and Technology (DST)	Director: Industry and Environments	5 September 2018
8	Kira Ross	South African Forestry Company Limited (SAFCOL)	Senior Manager: Business Optimisation and Special Projects	September 4, 2018
	Christiaan Smit		Specialist: Wood and Lumber	
Industry (including trade and membership associations)				
9	Arianna Baldo	Roundtable on Sustainable Biomaterials (RSB)	Lead: Africa/Middle East and Strategic Projects	October 15, 2018
10	Dr Johan de Graaf	Hans Merensky Holdings	Executive Manager: Merensky Timber	September 6, 2018

[89] As of July 2019, a restructure resulted in a departmental name change to Department of Environment, Fisheries and Forestry (DEFF).

[90] As of July 2019, a restructure resulted in a departmental name change to Department of Agriculture, Land Reform and Rural Development (DALRRD).

Interview ID	Name	Organisation	Job title	Interview date
Industry (including trade and membership associations) continued…				
11	Frans Hansen	Kimberly-Clark	Technical and Project Manager	September 4, 2018
12	Dr Ronald Heath	Forestry SA	Director: Research and Protection	October 15, 2018
13	Dr Arnulf Kanzler	Sappi	Program Leader: Tree Breeding, Shaw Research Centre	August 7, 2018
14	Dr Dirk Längin	Mondi SA	Forest Re-Engineering Manager	August 6, 2018
15	Mike Nash	Paper Manufacturing Association of South Africa (PAMSA)	Director: PAMSA Process Research Unit	September 6, 2018
16	Michael Peter	Forestry SA	Executive Director	September 5, 2018
17	Henry Reddy	LignoTech	Technical Services Manager	August 6, 2018
18	Petrus Saayman	Evergreen Timbers	Operations Director	August 7, 2018
19	Dr Nelson Sefara	Sappi	General Manager: Sappi Technology Centre	September 3, 2018
20	Roy Southey	Sawmilling SA	Executive Director	September 19, 2018
21	Grant Trebble	Independent	Project Advisor: Environmental Project Development	August 20, 2018
22	Jaco-Pierre van der Merwe	York Timbers	Wood Technologist	September 25, 2018
23	Anthony Williams	Citius Energy	Managing Director	September 12, 2018
Academia and research institutions				
24	Prof. Theo de Koker	Chemical Engineering, Durban University of Technology (DUT)	Head of Programme	August 8, 2017
	Dr Jimmy Pauck		Senior Lecturer	
25	Prof. Linda Godfrey	Council for Scientific and Industrial Research (CSIR) and Environmental Sciences and Management Unit, North-West University	Principal Scientist and Manager: Waste Research, Development and Innovation Roadmap Implementation	October 19, 2018
26	Prof. Bruce Sithole	Council for Scientific and Industrial Research (CSIR) and Chemical Engineering, University of KwaZulu-Natal (UKZN)	Principal Researcher and Director of the Biorefinery Industry Development Facility Professor of Chemical Engineering	August 9. 2017
27				August 1, 2018

Interview ID	Name	Organisation	Job title	Interview date
Academia and research institutions continued…				
28	Dr Douglas Trotter	Council for Scientific and Industrial Research (CSIR)	Competency Area Manager: Green Economy Solutions	August 1, 2018
29	Prof. Johann Görgens	Chemical Engineering, Stellenbosch University	Director: Centre for Process Engineering	September 8, 2018
30	Iain Kerr	Chemical Engineering, University of KwaZulu-Natal (UKZN) and Paper Manufacturing Association of South Africa (PAMSA)	Honorary Research Fellow	7 August 2017
31				8 August 2018
32	Dr Andrew Morris	Institute for Commercial Forestry Research (ICFR)	Acting Director and Research Manager	August 2, 2018
Civil society				
33	Tjaša Bole-Rentel	World Wide Fund for Nature South Africa (WWF-SA)	Project Manager: Bioenergy	August 31, 2018
34	Amanda Dinan	Fetola Foundation	Lead: Green Economy	August 31, 2018
35	Bhavna Deonarain	Trade and Industrial Policy Strategies (TIPS)	Researcher in Sustainable Growth	September 7, 2018
36	Saliem Fakir	World Wide Fund for Nature South Africa (WWF-SA)	Head: Policy Futures Unit	August 17, 2018
37	Jarrod Lyons	GreenCape and Wesgro	Liaison: Green Economy Investment and Finance	October 19, 2018
38	Dr Bongani Maseko	AfricaBio	General Manager: Agricultural Biotechnology	September 20, 2018
39	Bongani Mthembu	South Durban Community Environmental Alliance (SDCEA)	Air Quality/GIS and Youth Development Officer	August 31, 2017
40				August 3, 2018

Note 1: All leverage professionals gave consent to being named.

Note 2: Some fall within more than one actor group. They have been allocated to the actor group in which they are most active and known.

Note 3: Some leverage professionals were interviewed twice: once during the preliminary fieldwork, and again during the main fieldwork). This is indicated by two interview dates against their names. In some instances, two people were interviewed together. In such cases, they have been allocated one interview ID.

Appendix C
Technological innovation system functions

Function	Description	Indicators
***Function 1*: Entrepreneurial activities** (Hekkert et al., 2007; Uriona & Vaz, 2017) and experimentation (Bergek et al., 2010; Coenen, 2010; Markard, 2018; Walz et al., 2016).	*Entrepreneurial activities and experimentation* can be: − either new entrants, who see a new business opportunity, or incumbent companies established in the market looking for diversifying their business. *F1* is analysed by considering the number of new entrants, diversification activities of incumbent companies and experiments with the new technology (Hekkert et al., 2007; Uriona & Vaz, 2017); − diversity of solutions to allow for a sufficiently large stock of technologies enabling the selection process to result in a dominant design (Walz et al., 2016); and − conducting experiments, delving into uncertain applications and markets and discovering/creating opportunities (Bergek et al., 2008; Coenen, 2010).	− Number of new entrants (Hekkert et al., 2007; Uriona & Vaz, 2017) − Number of diversification activities (Hekkert et al., 2007; Uriona & Vaz, 2017) − Number of new experiments with a new technology (Hekkert et al., 2007; Uriona & Vaz, 2017) − Diversity of solutions (Walz et al., 2016)
***Function 2*: Knowledge development** (Bergek et al., 2008; Coenen, 2010; Hekkert et al., 2007; Markard, 2018; Uriona & Vaz, 2017) or generation (Walz et al., 2016).	*Knowledge development* encompasses “learning-by-searching” or “learning-by-doing” and is analysed by the number of R&D projects, patents, and investments in R&D (Hekkert et al., 2007; Uriona & Vaz, 2017).	− R&D projects over time (Hekkert et al., 2007; Uriona & Vaz, 2017) − Patents (Hekkert et al., 2007; Uriona & Vaz, 2017) − Investments in R&D (Hekkert et al., 2007; Uriona & Vaz, 2017)
***Function 3*: Knowledge diffusion through exchanging information in networks** (Bergek et al., 2010; Coenen, 2010; Hekkert et al., 2007; Markard, 2018; Negro, 2007; Uriona & Vaz, 2017; Walz et al., 2016).	*Knowledge diffusion* is: − the exchange of information between agents of the innovation system. This function is analysed by mapping the number of workshops and conferences on the subject and the network size (Hekkert et al., 2007; Uriona & Vaz, 2017); and − how knowledge is diffused and combined in the system (Coenen, 2010).	− Number of workshops and conferences on a particular technology (Hekkert et al., 2007; Uriona & Vaz, 2017) − The network size and intensity over time (Hekkert et al., 2007; Uriona & Vaz, 2017) − Knowledge sharing along the value chain (Walz et al., 2016)

Function	Description	Indicators
***Function 4*: Guidance of the search** (Bergek et al., 2008; Hekkert et al., 2007; Negro, 2007; Uriona & Vaz, 2017) or influence of direction (Coenen, 2010).	*Guidance of the search* refers to: − the activities of the innovation system that can positively affect the visibility of the technological needs. This function is mapped by identifying the focus of the research carried out by the agents and the number of articles published in journals that are related to the development of new technologies (Hekkert et al., 2007; Uriona & Vaz, 2017); and − what is directing R&D and the search for new solutions to allow a sufficiently large stock of technologies enabling the selection process to result in a dominant design (Walz et al., 2016).	− Specific targets set by governments or industries regarding the use of a specific technology (Hekkert et al., 2007; Uriona & Vaz, 2017). − Number of articles in professional journals that raise expectations about new technological development (Hekkert et al., 2007; Uriona & Vaz, 2017).
***Function 5*: Market formation** (Bergek et al., 2010; Hekkert et al., 2007; Markard, 2018; Uriona & Vaz, 2017; Walz et al., 2016).	*Market formation* is: − the creation of protected space for new technology market niches. This function is analysed by mapping the number of market niches, tax incentives for new technologies and new environmental standards (Hekkert et al., 2007; Uriona & Vaz, 2017); − the stimulation and creation of markets (Negro, 2007); and − the articulation of demand and more hard market development in terms of demonstration projects, nursing markets (niche markets), bridging markets and eventually mass markets (large-scale diffusion) (Bergek et al., 2008; Coenen, 2010).	− Number of niche markets that have been introduced (Hekkert et al., 2007; Uriona & Vaz, 2017) − Specific tax regimes for new technologies (Hekkert et al., 2007; Uriona & Vaz, 2017) − New environmental standards that improve the chances for new environmental technologies (Hekkert et al., 2007; Uriona & Vaz, 2017)
***Function 6*: Resource mobilisation** (Bergek et al., 2008; Bergek et al., 2010; Coenen, 2010; Hekkert et al., 2007; Markard, 2018; Uriona & Vaz, 2017; Walz et al., 2016).	*Resource mobilisation* involves: − mobilising financial resources and human capital, and controlling the extent to which such resources are available, and how fast such resources are redistributed to nurture the system (Bergek et al., 2008; Coenen, 2010; Hekkert et al., 2007; Uriona & Vaz, 2017); − supplying incentives for companies to engage in innovative work (Negro, 2007); − supplying resources (capital and competence) (Negro, 2007); and − building competence (Lundvall, 1992).	− Funds made available for long-term R&D programmes set up by industry or government to develop specific technological knowledge (Hekkert et al., 2007; Uriona & Vaz, 2017) − Funds made available to allow testing of new technologies in niche experiments (Hekkert et al., 2007; Uriona & Vaz, 2017) − Perception of the actors regarding the access to sufficient resources (Hekkert et al., 2007; Uriona & Vaz, 2017)

Function	Description	Indicators
***Function 7*: Legitimisation of a new technology or counteract resistance to change** (Bergek et al., 2008; Bergek et al., 2010; Coenen, 2010; Hekkert et al., 2007; Markard, 2018; Uriona & Vaz, 2017; Walz et al., 2016).	*Legitimising new technology* or *counteracting resistance to change* entail: − the appearance of coalitions defending the entrance of new technologies and minimising the resistance to change. This function is analysed by mapping the group or groups defending the legitimacy of these technologies (Hekkert et al., 2007; Uriona & Vaz, 2017); − the recognition of the growth potential for the technology and the ability to counteract political resistance and to push for political support (Negro, 2007; Walz et al., 2016); − the formation of expectations and visions, as well as a regulatory environment; for example, market regulations, tax policies or the direction of science and technology policy (Bergek et al., 2008; Coenen, 2010); and − political visions and goals (Hellsmark et al., 2016).	− Rise and growth of interest groups (Hekkert et al., 2007; Uriona & Vaz, 2017) − Lobby actions (Hekkert et al., 2007; Uriona & Vaz, 2017)

Appendix D
Hybrid classification of individual team network roles[91]

Belbin team role type	Belbin role description	Aligned similar classifications
Coordinator	− Mature, confident, identifies talent − Clarifies goals − Coordinates and controls team activities − Can be seen as manipulative and might offload their own share of the work − Might over-delegate, leaving themselves little work to do	***Boundary spanner*** − Coordinates to support and find areas of mutual benefit − Offers some form of leadership and control − Provides representation, internal influence and service delivery − Task of bringing actors (experts, decision-makers, other stakeholders) together to co-produce applied knowledge or tools ***Broker*** − Has an integrative work approach/ethic − Encourages the value of cooperation ***Change agent*** − Responsible for initiating, sponsoring, directing, managing or implementing a specific change initiative − Facilitator
Resource-investigator	− Uses their inquisitive nature to find ideas to bring back to the team − Outgoing (extrovert), enthusiastic − Explores opportunities and develops (outside) contacts − Might be over-optimistic and can lose interest once the initial enthusiasm has passed − Might forget to follow up on a lead	***Boundary spanner*** − Is an individual who straddles two or more groups or individuals − Carries out research to support and share between groups or individuals, ultimately to find areas of mutual benefit − Is an advocate of the company (organisation) − Obtains feedback and perceptions from the external environment through their stakeholder networks and transitioning information back into their organisation ***Broker*** − Individuals who harness the advantage networking offers − A person who can bridge structural holes or gaps between groups or clusters − Facilitate the flow of knowledge between/across “actors” ***Intermediary*** − Enhance local innovation and capacity by connecting, for example, foreign technology providers with local users ***Change agent*** − Excels at harnessing the advantage networking offers

[91] Adapted from, and informed by: Agnihotri et al., 2014; Aldrich & Herker, 1977; Alexander et al., 2016; Allio, 2011; Ansett, 2005; Appelbaum et al., 2007; Belbin, 2019; Burt, 2001, 2005; Chen et al., 2015; Ernst & Chrobot-Mason, 2011; Flores-Parra et al., 2018; Grandia, 2015; Hill, 2012; Hoffman & Haigh, 2011; Hsu et al., 2007; Kraft, 2017; Lundberg, 2013; Marsh et al., 2004; Meyerson, 2001, 2004; Pascale et al., 2011; Safford et al., 2017; Seidman & McCauley, 2008; Sparks, 2005; Todo et al., 2016; Tushman & Scanlan, 1981; Van Poeck et al., 2017.

Belbin team role type	Belbin role description	Aligned similar classifications
Team worker	− Helps the team to gel, using their versatility to identify the work required and complete it on behalf of the team − Cooperative, perceptive and diplomatic − Listens and averts friction − Person oriented, communicates well with others − Can be indecisive in crunch situations and tends to avoid confrontation − They might be hesitant to make unpopular decisions	***Boundary spanner*** − Effective at understanding the "coding schemes" and contexts of both sides of the boundary, which enable them to interpret, pre-empt or respond to the dynamic nature of interaction and changes − Filters, transacts, buffers and protects − Mediating contact between two members of its own group. (coordinator) and between and outsider and a member of its own group (gatekeeper) − Mediating conflicting demands and expectations by means of personal communication − Facilitates the creation of a common perspective ***Broker*** − Integrative work approach/ethic ***Change agent*** − Listen, reflect and cooperate
Plant	− Tends to be highly creative and good at solving problems in unconventional ways − Imaginative, free-thinking, generates ideas and solves difficult problems − Might ignore incidentals and may be too preoccupied to communicate effectively − They could be absent-minded or forgetful	***Boundary spanner*** − Sometimes described as invention factories. ***Broker*** − Tend to have more creative ideas and more likely to see a way to implement ideas ***Change agent*** − Visionaries − Challenges world views and pathways, attitudinal and behavioural patterns ***Tempered radical*** − Wants to succeed in their own organisation yet wants to live by their own values or identities − Because of their experiences, they see things others don't see ***Positive deviant*** − Recognised for departing from established paths or norms, and being successful at it, yet do not create conflict − Consistently discover new and innovative ways to function − Innovative − Bring passion, energy, vitality and commitment to their work, and operate at higher levels of intensity than most
Monitor-evaluator	− Sober, strategic and discerning − Sees all options and judges accurately − Sometimes lacks the drive and ability to inspire others and can be overly critical − They could be slow to come to decisions	***Boundary spanner*** − Address each party's needs and identify potential spaces of "strategic overlap" where possible collaboration can take place − Serve strategic roles in organisations by gathering critical information ***Positive deviant*** − Have a sense of sacredness and purpose through their work that allows them to feel more genuine and authentic

Belbin team role type	Belbin role description	Aligned similar classifications
Implementer	− Needed to plan a workable strategy and carry it out as efficiently as possible − Practical, reliable and efficient − Turns ideas into actions and organises work that needs to be done − Can be a bit inflexible and slow to respond to new possibilities − They might be slow to relinquish their plans in favour of positive changes	***Boundary spanner*** − Recognised as competent, trustworthy, and hold some form of status within and between groups and perform well within their jobs − Produce boundary products or tools that enable communication between these two groups − Information acquisition and delivery − Localisation of knowledge and identification, redistribution and dissemination, as well as rescaling and transformation ***Change agent*** − Develop ideas and approach through networking with aim to activate a critical mass
Completer-finisher	− Painstaking, conscientious, and anxious − Searches out errors − Polishes and perfects − Can be inclined to worry unduly, and reluctant to delegate − They could be accused of taking their perfectionism to extremes	
Shaper	− Challenging, dynamic, thrives on pressure − Has the drive and courage to overcome obstacles − Can be prone to provocation and may sometimes offend people's feelings − They could risk becoming aggressive and bad humoured in their attempts to get things done	***Change agent*** − Catalyst and activist, challenge world views and pathways, attitudinal and behavioural patterns − Provide others with constant motivation for self-sustaining change ***Tempered radical*** − Operate on the fault line − Overcome obstacles by "chipping away" at initiatives that act as "small wins" on a path to lasting change − Hold onto deepest goals to push through fears and to choose their battles effectively ***Positive deviant*** − Recognised for departing from established paths or norms, despite facing similar challenges, resource and knowledge as their peers − Bring passion, energy, vitality and commitment to their work, and operate at higher levels of intensity than most − Critique of the *status quo*

Belbin team role type	Belbin role description	Aligned similar classifications
Specialist	− Brings in-depth knowledge of a key area to the team. − Single-minded, self-starting and dedicated − Provide specialist knowledge and skills − High technical skills and in-depth knowledge for the task − Tends to contribute on a narrow front and can dwell on the technicalities − They overload you with information.	***Boundary spanner*** − Perceived as credible experts − Information search or research-focused where external. relationships are primarily with universities, research institutions and so on − Superior access to diverse information ***Broker*** − Facilitate the flow of knowledge between/across "actors"

Appendix E
South African biorefinery research platform list of research projects

Waste feedstock	Academic and Research Institution	Research title
Cereal derived wastes	CSIR	Sustainable utilisation and conversion of post-harvest agricultural waste residues into value added materials.
	Northwest University	Microwave-assisted biobutanol production from biomass using nano based metal oxides as catalysts.
	Northwest University	Identification of lignocellulolytic enzymes from pathogenic fungi.
	Stellenbosch University	Organic waste: A bioresource for production of novel cellulose nanocomposites.
	Stellenbosch University	Biorefineries based on brewers' spent grain.
Confectionary derived wastes	University of Cape Town	Value recovery from chocolate and sugar confectionery waste.
	University of Cape Town	Production of (Poly-γ-Glutamic acid) PGA from candy waste using *Bacillus sp.*
Fish-related wastes	Stellenbosch University	Valorisation of low value fish processing waste: Optimisation of enzymatic protein hydrolysis of fish processing waste.
	Stellenbosch University	Development of high-value, organic fertilisers through enzymatic protein hydrolysis of fish processing waste.
	Stellenbosch University	Valorisation of low value fish processing waste: Determining nutritional quality of fish protein hydrolysates and phosphorous supplements in animal diets.
Forestry and forest product derived wastes	CSIR	Production of nano-crystalline cellulose (NCC) from sawdust waste material.
	CSIR	Lignosulphonate sludge.
	CSIR	Beneficiation of sawdust waste: Fractionation of hydrophilic compounds.
	CSIR	Valorisation of bark components.
	CSIR	Beneficiation of green liquor dregs.
	CSIR	Biosynthesis of polyhydroxyalkanoate (PHA) and poly lactate polymers by recombinant bacteria on mill sludge.
	CSIR	Beneficiation of pulp and paper mill sludge into value added products: Biogas and compost.
	Stellenbosch University	Enzymatic methods of isolating nanocelluloses from paper sludge.
	Stellenbosch University	Pyrolysis for production of high value phenolics from lignin isolated from waste streams.
	Stellenbosch University	Upgrading of lignocelluloses prior to co-gasification with coal.
	Stellenbosch University	Production of terephthalic acid from forestry residues and condensates of digestor off gases in a pulp mill.

Waste feedstock	Academic and Research Institution	Research title
	Stellenbosch University	Co-production of ethanol and biogas from paper sludge waste, with process scale-up.
Fruit derived wastes	CSIR	Valorisation of fruit and vegetable waste into value added products: biogas and compost.
	Stellenbosch University	Biogas and volatile fatty acids biorefinery by co-digestion of fruit juice industry solid and liquid wastes with lignocellulosic biomass.
	Stellenbosch University	Organic waste: A bioresource for production of novel cellulose nanocomposites.
Meat derived wastes	CSIR	Valorisation of waste chicken feathers.
	Northwest University	Setting the basis for the development of a national standard for the grading of biogas.
	Northwest University	Co-digestion of slaughterhouse waste (SHW) and cow dung (CD) to enhance biogas production and ascertain optimum mixing ratios.
	Northwest University	Process design and techno-economic evaluation of a bio-refinery using lignocellulosic biomass feedstock.
Sugar production derived wastes	CSIR	Sustainable utilisation and conversion of post-harvest agricultural waste residues into value added materials.
	Stellenbosch University	Reactor design for industrial furfural production from sugar cane agricultural residues.
	Stellenbosch University	Co-production of furfural and ethanol in sugarcane lignocellulose biorefineries.
	Stellenbosch University	Simulation of biorefinery scenarios for sugarcane lignocelluloses, annexed to existing sugar mills.
	Stellenbosch University	Co-production of lactic acid and ethanol in sugarcane lignocellulose biorefineries.
	Stellenbosch University	Co-production of hemicellulose biopolymers and bioethanol in lignocellulose biorefineries.
	University of Cape Town	Integrated process flow sheets for vinasse management technology.
	University of Cape Town	Value addition to sucrose in South Africa: A techno-economic and environmental study.
	University of Cape Town	Optimisation of fermentation for bioethanol production from mixed xylose and glucose using immobilised cultures: mathematical model and experimental observation.
	University of Cape Town	Feasibility of value addition of sucrose to platform chemicals in South Africa.
	University of Cape Town	Bioremediation of vinasse with associated value recovery through its pre-treatment and anaerobic digestion.
	University of Cape Town	Improving butanol fermentation from sucrose.
Vegetable derived wastes	Stellenbosch University	Dietary protein in a yellow pea biorefinery.
	Stellenbosch University	Co-production of protein, prebiotics and ethanol from Jerusalem artichokes in a biorefinery.

Waste feedstock	Academic and Research Institution	Research title
Wastewater	University of Cape Town	Wastewater biorefineries.
	University of Cape Town	Investigation of the trade-offs between methane productivity and yield in wastewater anaerobic digestion.
	University of Cape Town	Value from Waste: Reactor selection in the production of valuable bioproducts from wastewater.
Other	CSIR	Desalination of bleach plant effluents.

Appendix F
Full set of descriptions and definitions provided by leverage professionals on their understanding of biorefinery technologies and products

Leverage professional or entity	Biorefinery technology or products description
Government	
Johann Bester, DAFF	*He noted that the biorefinery applications concept is a "bit off his radar":* "It is the process of extraction of chemical components from raw materials (e.g., wood waste, bagasse, sludges, etc.) and the refinery or purification of the extracted target substances." (Interview 2, August 10, 2018)
Sunita Kalan, DST	*She noted her understanding comes from not being a biorefinery technician:* "Using biomass, whether that's forestry or chicken feed, and using the waste material that comes out of it to beneficiate and make new products or new applications for those products." (Interview 3, September 5, 2018)
Steven Ngubane, IDC	*From the context of the forestry value chain:* "It is a chemical process aimed at extracting valuable nutrients from a wood-based material. This will probably vary in other sub-value chains in the industry, for example sawmilling. The conventional product there is structural industrial timber, and the byproduct will be sawdust. That becomes the raw material for the biorefinery process. … It is a chemical process aimed at advancing the benefits that can be derived from the value chain over and above the conventional understanding of the wood-based industry." (Interview 4, August 2, 2018)
Henry Nuwarinda, NCPC	"The reprocessing of wood or timber products into bioproducts, such as biodiesel or biofuel." (Interview 5, October 16, 2018)
Tafadzwa Nyanzunda-Kadzombe, DTI	*From the perspective of economic prospects and growth contribution to the South African economy:* "Releasing cellulose and sugars when the components are broken down from a tree. … a number of interesting products are coming out of this. … it can go into automotive products, pharmaceuticals and the food industry." (Interview 6, September 25, 2018)
Dr Konanani Rashamuse, DST	*He has an in-depth understanding of the biorefinery value chain, having developed and worked on the DSTI's biorefinery strategy (yet to be published):* "Typically, a value chain for a biorefinery has an upstream (such as primary agricultural production). … First-generation biorefineries refer to starch-based feedstock, and then you have second generation biorefineries, which look at lignocellulosic ethanol, and third generation, with multiple feedstocks and multiple products." (Interview 7, September 5, 2018)
Kira Ross, SAFCOL	*From the perspective of not being dedicated to biorefineries:* "Biorefineries are looking for alternative products to the normal oil-based products. … producing something of value. … sustainable products. … use of bioproducts." (Interview 8, September 4, 2018)

Leverage professional or entity	Biorefinery technology or products description
Government continued…	
Christiaan Smit, SAFCOL	*He noted his perspective is determined by not being dedicated to biorefineries and is not familiar with the details of what SAFCOL is doing in this area:* “To get cellulose from it [wood] and to use material, we are sitting with efficiently as an energy source in co-fraction or co-generation. … it is a process that can break a raw material down to get a very high value product. Wood is not that high value a product but getting something like xylitol or furfural that you can produce and sell …”. (Interview 8, September 4, 2018)
Industry	
Dr Johan de Graaf, Hans Merensky Holdings	*He noted his definition is from the perspective of a sawmiller and seeing value in byproducts:* “Any byproducts of high value that allows us to enter into higher markets. Maybe substitutes … new value chains … like crystalline cellulose, which can be used in dairy products to clothes to cell phone screens. So, it can have a wide application. Other things like low-calorie sugars – xylitol.” (Interview 10, September 6, 2018)
Frans Hansen, Kimberly-Clark	“Solutions from waste.” (Interview 11, September 4, 2018)
Dr Ronald Heath, Forestry SA	*Noted he doesn’t understand the technical detail but has a strategic view* (Interview 12, October 15, 2018). *He does not provide enough detail to generate a definition*.
Dr Dirk Längin, Mondi SA	*This is from the perspective that bioenergy is a “side-line job”, and he stressed he is not a process engineer:* “A biorefinery plant uses natural, renewal products to develop a product which could be liquid gas, which is a sustainable product – gasses, liquid fuels – out of biomass in the broader sense. A plant that doesn’t just burn biomass for the sake of energy generation. … bioenergy is firewood or biomass for electricity generation.” (Interview 14, August 6, 2018).
Michael Peter, Forestry SA	“Biorefineries produce a variety of products such as biopolymers and chemical cellulose. … A biorefinery is any facility that optimises the possible range of products that could be produced from a given feedstock, as opposed to a processing plant that is unidirectional, in that it has two or three given product lines. You could put all your black liquor through the recovery boiler, all your sawmill’s fines into a plant. … the optimal use of the entire feedstock that comes into the biorefinery.” (Interview 16, September 5, 2018).
Henry Reddy, LignoTech	*While working for a biorefinery company, he noted having a very limited understanding of biorefineries:* “It’s probably the digester or some sort of big pressure vessel through which different types of raw materials are fed. You can cook, digest and from there convert into some sort of saleable product. The raw materials could be a byproduct from another industry, such as maize.” (Interview 17, August 6, 2018).
Petrus Saayman, Evergreen Timbers	*From the perspective of a sawmiller, who noted that some terms are over his head:* “A sawmiller sees a biorefinery as producing woodchips for better or cleaner fuel, as opposed to fossil fuels. Many other products can be extracted out of wood chips – sugars and other chemicals, such as xylitol. Cellulose can go into clothing, and there’s a lot more than just using it for fuel.” (Interview 18, August 7, 2018).

Leverage professional or entity	Biorefinery technology or products description
Industry continued…	
Dr Nelson Sefara, Sappi	*From the perspective of having generated and applied in-house knowledge on biorefineries:* "A biorefinery is any technology that attempts to extract new material and new products that are outside of the general scope of beneficiation. The ways that we use wood are for structural purposes or for making paper, which is probably the biggest use. Anything outside of this you are now making secondary products either by adding chemicals or even classifying energy products from wood, e.g., firewood. Other products include bio-oil and polymers. … Biotechnology is the mechanical or biological way of fermentation, and there are chemical conversion processes. … other processes include taking waste or sludge from our existing operations and extracting from them chemicals or manufacturing them into other products, which are considered biodegradable." (Interview 19, September 3, 2018).
Roy Southey, Sawmilling SA	*From the perspective of the sawmilling industry, and technology that is "foreign to sawmills:* "It is the concept of turning biowaste or biomass from sawmills into energy. … producing xylitol and nanocrystalline cellulose. … Distilling various chemicals to obtain products. … It is the extraction of unusual products from solid timber to produce oils and volatiles and cellulose products." (Interview 20, September 19, 2018)
Grant Trebble, independent	*From an alien vegetation or biomass perspective and not having "got my hands dirty in that field":* "The extraction of fuel from cellulose products that could be easily used for fuel other than just burning timber. I'm not sure if pellets fall into biorefinery or not … in my mind I loosely see a biorefinery product as liquid, so aviation fuel, vinegars and those sorts of things. … waste converted to a higher value product." (Interview 21, August 20, 2018)
Jaco-Pierre van der Merwe, York Timbers	"To transform wood or timber into something that is usable. A refinery means basically to refine something, and so I think a biorefinery is not necessarily limited to wood. I think it's anything that's biological. It can be food waste; it can be timber. Byproducts can be used." (Interview 22, September 25, 2018)
Academia and research institutions	
Prof. Linda Godfrey, CSIR	*She noted she is not directly involved in biorefinery research:* "It is a technology that provides maximum value and includes recovery from primary and secondary biomass resources. … a variety of products, like the traditional refinery – it could be fuel, it could be chemicals. High value products. One of the lowest values would be composting." (Interview 25, October 19, 2018)
Prof. Johann Görgens, Stellenbosch University	"There's a list of fifty products. When we talk about biorefineries, pelletisation is a simple technology. In biorefineries, I'm talking about a lot more complicated technologies to make, e.g., succinic acid. … It's an industrial facility, which means a paper and pulp mill or a sugar mill or Sasol. … the easiest way to define a biorefinery is to look at the products, say producing ethanol. This is a conventional technology, but it's still considered a biorefinery to people who produce ethanol." (Interview 29, September 8, 2018)

Leverage professional or entity	Biorefinery technology or products description
Academia and research institutions continued…	
Iain Kerr, UKZN	"[T]o extract the most value out of woods or whatever material you are working with and break it down into its components. Then you can take the cellulose and convert it to nanocellulose or into other polymers … there's a whole range of things. … It's the conversion of a raw material into a high valued product and using every component of that raw material. There are other energy products you can get from wood if you apply pyrolysis or gasify it and process it into fuels or burn it for energy. That's all part of the biorefinery technology. … branching out into a range of products from a raw material that previously was only used for pulp and paper." (Interview 31, August 8, 2018)
Dr Andrew Morris, ICFR	"[A] tree can give you multiple products, it doesn't have to be reduced to a cellulose feedstock. … it could be reducing it chemically, or it's just the wood you're seeking with other products as an addition – tannin from bark would be an example." (Interview 32, August 2, 2018)
Prof. Bruce Sithole, CSIR	"[W]ood is compiled of hemicellulose, lignin … if you are making paper, all you want is the cellulose, the rest is considered waste. … Sugar can be extracted and converted into something else, for example xylose, and from there into xylitol. … from pine, pine oils can be extracted. … from sawdust, nanocrystalline cellulose, so there is no more waste. Extracting maximum value from the tree. … a byproduct of producing pulp is lignosulfonates which are being used to make binders for, e.g., road surfacing. So, in the case of biorefineries, you are refining it into different types of products, the same materials and chemicals that you'd obtain from oil and coal, you obtain them from, e.g., wood biomass. … it is taking biomass and refining it into different products, chemicals and materials. … the higher value materials are chemicals, and these are obtained in small quantities." (Interview 27, August 1, 2018)
Dr Douglas Trotter, CSIR	*From the perspective of how biorefineries fit within the pulp and paper and the forestry sectors, but noted he is not a chemical engineer:* "A whole new value chain could be created from waste woods and sawdust material. … A biorefinery has applications beyond forestry; it goes into agro-processing and into a whole range of things. … to use biomass resources more efficiently. The products are very broad: there are energy products, high value chemicals and biomaterials – chemical replacement products, or niched products." (Interview 28, August 1, 2018)
Civil society	
Tjaša Bole-Rentel, WWF-SA	"A biorefinery is a set of processes that are brought together to extract the maximum value of the biomass. Most types of biomass can give more than one product and can be processed into multiple products. A biorefinery is a place under one roof where multiple products and value streams can be produced from your base material, typically fuels and chemicals … biofuels. You can use corn and grain to produce fuel, and the wood residue (e.g., leaves) to produce fuel through processing routes or you can make any other product from it." (Interview 33, August 31, 2018)
Bhavna Deonarain, TIPS	*She acknowledged that she is not an expert in this field but has a basic knowledge from carrying out research on the topic:* "It uses feedstock, such as maize or sugar or byproducts or waste to produce a spectrum of chemicals or composites. … With a biorefinery, you'd be able to maximise the use of a tree and extract the fibres. From each different crop, there are different processes and different outputs." (Interview 35, September 7, 2018)

Leverage professional or entity	Biorefinery technology or products description
Civil society continued	
Saliem Fakir, WWF-SA	*He noted he is not competent to provide a comment on uses other than biofuel and that he is not a biorefinery expert:* "My understanding of a biorefinery is that you can have a process which is governed by the biological activity of the material; in this case, that could be micro-organisms, like specific types of bacteria. It could be things like yeast, fungi … using microbiological life to generate a particular chemistry pathway that is able to generate products … beer, medicines, future bioplastics, fuel like ethylene, etc. The biorefinery is the physical thing, like a bioreactor. It is the real science and the choice of the microbial life one selects, and you can do it in the classical way where you don't do any genetic engineering and you experiment with microbes … or you can do genetic engineering. … you use the components in micro to create a bioreaction." (Interview 36, August 17, 2018)
Jarrod Lyons, GreenCape	*He noted he has a broad understanding, coming from a molecular background. He states he has a better knowledge of biomass and alien vegetation as a feedstock:* "Chemical or bio-molecular production from biological material. It is a molecular conversion of biological material. … a little bacterium and you manipulate its genes and it produces an enzyme for you." (Interview 37, October 19, 2018)
Dr Bongani Maseko, AfricaBio	"It is a chemical or mechanical process in which the lignin content of wood chips is difficult to extract. Using biotech or bioengineering could assist in doing this. … even producing value-added products or bioproducts including charcoal." (Interview 38, September 20, 2018)