Titanium beneficiation in South Africa: A product space and location-centric analysis

by

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Abstract

The advantages and disadvantages of introducing mineral beneficiation initiatives and policies in developing countries such as South Africa, which are endowed with abundant natural mineral resources, have been the subject of debate for decades. Proponents of such strategies argue that mineral-rich developing countries should introduce policies that allow them to realise more economic benefits from their natural mineral bases. It is believed that by growing their productive capabilities, countries can increase the number of complex products they produce, and in doing so, support long-term economic growth that is less dependent on mineral resources. If value can be added locally to the raw minerals by moving further down specific value chains, such countries' economic and social benefits might be significant. Within this context, this study investigates titanium-related beneficiation initiatives in South Africa. The country is one of the biggest titanium mineral reserve holders globally. Based on historical experience with beneficiation-related policies, it is clear that such initiatives often fail, and that well-considered approaches are required if such policies are to be successful.

Thus, this study attempted to identify specific undeveloped target sectors within the titanium value chain that could support the country's developmental goals. Furthermore, it sought to identify the key factors that would need to be in place to enable such industries to operate successfully. Identifying sectors that are deemed within reach and similar to those of South Africa's current productive structure, whilst also supporting the development of new capabilities to "unlock" new sectors, forms the foundation of the study. By mapping out the titanium value chain using trade codes and drawing on trade data, the extent of South Africa's current footprint in the global value chain is evaluated. Further evaluation of South Africa's existing footprint regarding current firms and research initiatives is also used to enhance the evaluation. Based on the results of this evaluation, the most promising product categories for South Africa to target are identified for further analysis. Initial results indicate that product categories such as steam turbines and paint pigments can be considered product categories with significant potential.

The identified industry is evaluated using key factors that affect global competitiveness for the identified industry at specific locations. By identifying the key factors that drive global competitiveness for an industry, specific interventions that would be necessary to support the development of the industry can be identified. The steam turbine industry is evaluated against the key

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factors, allowing interventions to be guided more accurately by targeting the most important factors identified for the industry.

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Opsomming

Die voordele en nadele van die inwerkingstelling van mineraalveredelingsinisiatiewe- en - beleide in ontwikkelende lande soos Suid-Afrika, wat oorvloedige natuurlike minerale bronne het, is die afgelope paar dekades die onderwerp van debat. Voorstanders van die strategieë argumenteer dat mineraalryke ontwikkelende lande beleide moet instel wat hulle in staat sal stel om meer ekonomiese voordele uit hul natuurlike minerale hulpbronne te bekom. Daar word geglo dat die lande, deur hul produktiewe vermoëns uit te brei, die aantal komplekse produkte wat hulle produseer kan verhoog. So word die ekonomiese groei op die langtermyn ondersteun en raak minder afhanklik van minerale bronne. As waarde tot rou minerale plaaslik bygevoeg kan word deur verder af te beweeg in spesifieke waardekettings, kan die ekonomiese en sosiale voordele vir sulke lande beduidend wees.

Binne hierdie konteks ondersoek hierdie studie titaan in Suid-Afrika, as die land met een van die grootste titaanreserwebronne ter wêreld. Op grond van historiese ervaringe met beleide ten opsigte van veredeling, is dit duidelik dat sulke inisiatiewe dikwels misluk, en dat weldeurdagte benaderings nodig is om ń sodanige beleid te laat slaag.

Hierdie studie het gepoog om spesifieke onontwikkelde teikensektore binne die titaniumwaardeketting te identifiseer wat die ontwikkelingsdoelwitte van die land kan ondersteun. Verder is daar gepoog om die belangrikste faktore te identifiseer wat nodig is om sodanige bedrywe suksesvol in die land te kan laat funksioneer. Die indentifikasie van sektore wat binne bereik en soortgelyk geag kan word aan die huidige produksie-strukture in Suid-Afrika terywl dit ook die ontwikkeling van vermoëns ondersteun om nuwe sektore te ontsluit, vorm die gronslag van die studie.

Deur die titaniumwaardeketting te karteer met behulp van handelskodes en -data, word die omvang van Suid-Afrika se huidige voetspoor in die globale waardeketting beoordeel. Op grond van die resultate van hierdie evaluering word die mees belowende produkkategorieë waarop Suid-Afrika kan fokus, geïdentifiseer vir verdere ontleding. Op grond van die resultate word produkkategorieë soos stoomturbines en verfpigmente aanvanklik beskou as die kategorieë met die meeste potensiaal. By nadere ondersoek is stoomturbines geidentifiseer as die industrie met die grootste potensiaal. Die onderliggende struikelblokke wat gedurende die studie aan die lig gekom het, het gelei tot die verfyning van die aanvanklike evaluering van die titaniumwaardeketting. Groter klem is geplaas op

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Suid-Afrika se huidige produksie-struktuur. Dit het bevestig dat dit die moeite werd is om stoomturbines verder te ondersoek.

Die geïdentifiseerde bedryf word beoordeel aan die hand van sleutelfaktore wat die wêreld se mededinging vir elk van die geïdentifiseerde bedrywe beïnvloed. Deur die sleutelfaktore te identifiseer kan spesifieke ingrypings wat nodig is, geïdentifiseer word.

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Glossary

Acronyms and Abbreviations

AIP	Appropriate Industrial Policy
AMI	Advanced Metal Initiative
AMTS	National Advanced Manufacturing Technology Strategy
CIP	Critical Infrastrucutre Program
CSIR	Council for Scientific and Industrial Research
CUT	Central University of Technology
DST	Department of Science and Technology
DTI	Department of Trade and Industry
ECI	Economic Complexity Index
FDI	Foreign Direct Investment
GRIG4	Global Reporting Initiatives G4 Sustainability Reporting Guidelines
GVC	Global Value Chain
HS	Harmonised System
IO-PS	Input Output-Product Space
IP	Intellectual Properties
IPAP	Industrial Policy Action Plan
LMDM	Light Metals Development Network
MIP	Manufacturing Investment Programme
MPRDA	Mineral and Petroleum Resources Development Act
NACI	National Advisory Council of Innovation
NESCA	The South African Nuclear Corporation SOC Limited
NGP	New Growth Path
NMMU	Nelson Mandela Metropolitan University
OG	Opportunity Gain
OV	Opportunity Value
PCI	Product Complexity Index
PCU	Potential Catching Up
PS	Product Space
RBIT	Richards Bay Minerals and Titanium

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RBM	Richards Bay Minerals
RCA	Revealed Comparative Advantage
SITC	Standard International Trade Classification
SU	Stellenbosch University
TBI	Titanium Beneficiation Initiative
TIA	Technology Innovation Agency
TICP	Technology Innovation Cluster Programme
TiCoC	Titanium Centre of Competence
UCT	University of Cape Town
UJ	University of Johannesburg
VC	Value Chain
VUT	Vaal University of Technology

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Chapter 1

Introduction

"History and societies do not crawl. They make jumps. They go from fracture to fracture, with few vibrations in between. Yet we, and historians, like to believe in the predictable, small incremental progression" – Nassim Nicholas Taleb.

Titanium has been identified as one of the mineral resources that South Africa has in abundance and which has the potential to serve the country as a strategic economic driver. Due to its unique physical and chemical properties, titanium's various possible applications open up numerous potential opportunities for South Africa to establish local titanium-based industries (Van Tonder, 2010). The potential beneficial gains for South Africa by expanding its footprint in the global titanium value chain and becoming competitive in new parts of this value chain could be significant in terms of socio-economic benefits. Recent research into the titanium industry is pushing the boundaries in the search for more cost-effective processes to produce titanium. If local technology delivers on the cost-reductive processes that researchers have been investigating, it could increase momentum and interest in developing the South African titanium industry (Butts and Gale, 2003 and van Tonder, 2010).

Thus, this study aimed to analyse the titanium value chain and assess which segments and industries would potentially add the most value to the South African economy as well as assess how well-equipped South Africa is to support these industries. Investigating the country's existing capabilities and the potential of new opportunities were key to attaining the aims of the study. Although it is important for countries to establish themselves in value chains, insertion initiatives can be costly, as these require new investments and often also the development of new skills and capabilities. One of the major obstacles is identifying where the opportunities lie within the titanium value chain, which therefore requires thorough research (Van Vuuren, Engelbrecht and Hadley, 2005). Thus, such insertion initiatives should be targeted as strategically as possible to ensure maximum benefit – hence the importance of this study.

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National priorities such as economic growth should be the focal objectives when evaluating industries. Through mapping and analysing the titanium value chain, it was possible to analyse which production and processing activities appear the most promising in an attempt to establish the optimality of different development routes. The most eligible sectors in the titanium value chain based on the country's short- and long-term development strategies could be identified accordingly and further analysed to determine how they might best be targeted. Evaluating how these key industries might be targeted was crucial to establish how government might best support these industries. Key industry-related dynamics needed to be established to assess South Africa's current shortfalls, and the realistic potential for both entering the relevant markets and being competitive within them.

In the following section (Section 1.1) a brief background to the study is provided, focusing on the potential opportunities that titanium could provide for South Africa and the significance of the research for South Africa. The problem statement for this thesis is stated in Section 1.2, followed by the research aim and research objectives in Sections 1.3 and 1.4, respectively. Finally, the thesis's overall structure and flow are shown in Section 1.5.

1.1. Background

The African continent is richly endowed with mineral resources – especially countries on the southern parts of the continent. This includes South Africa, which has large amounts of natural resources. Titanium, which has been identified as a mineral resource with the potential to act as a strategic economic driver for the country, falls into the class of abundant minerals. The mineral industry has been a significant driver of South Africa's economy for more than a century. In a report by CitiBank in 2010, an independent evaluation of South Africa's mineral wealth was estimated to be at US$2.5 trillion, making South Africa one of the world's wealthiest mining jurisdictions (Department of Mineral Resources, 2011). Data from (USGS, 2019) indicates that, of the approximate US$9 billion titanium industry, 20% of the raw titanium-bearing materials are supplied by South Africa. South Africa only processes about 5% of all the raw titanium-bearing minerals that are mined in the country; the rest is exported. South Africa as of yet does not contribute to any major downstream beneficiation activities producing titanium metal, titanium dioxides or any other value-added products (Van Vuuren, 2009).

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South Africa has failed to capitalise on this rich mineral reserve's potential, as most of the country's mineral resources are exported as raw ores or only partially processed. The government's industrial policy is attempting to make a shift in mineral developments through strategic investments in assets to maximise long-term growth of beneficiation projects, enhance the value of exports and create local manufacturing opportunities that allow for more sustainable jobs (Department of Trade and Industry, 2016). Although the government's industrial policy plan has a clear vision, there is still a shortfall in the methods used for assessing which segments in the value chains are realistically worth the investments, and what the key factors are that would be required for the government to support them.

Van Vuuren et al. (2005) and du Preez (2014) have previously discussed the potential national and socio-economic benefits that could arise if a local titanium industry could be established, namely:

- A titanium metal plant can be expected to generate a revenue of about US$400 million per annum. This revenue can increase to almost US$1 000 million per annum once a downstream industry for the production of semi-finished products has been fully developed;
- Once a titanium industry has been established, it will present the opportunity for numerous downstream manufacturing enterprises to be established, which is not possible without a local titanium industry;
- Local job creation downstream in the titanium value chain could bring about 1 500 permanent jobs. These industries, in turn, allow for establishing numerous small and medium enterprises as well as complementing black economic empowerment; and
- A large part of South Africa's importation of about 800 tons of titanium in various forms can be replaced, saving approximately US$5 million per annum in foreign exchange rate losses.

Industrialisation based on titanium mineral resources is constrained by various obstacles. The biggest obstacle as well as the primary reason for the high titanium metal price is the antiquated technology used to extract the metal from raw materials (Van Vuuren, 2009). Among potential replacement processes being developed worldwide, processes under development in South Africa include the Peruke and CSIR processes. The Peruke process has been under development by the Anglo-American corporation. At the same time, the CSIR is sponsored by

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the Department of Science and Technology (DST). Yet, no alternative process has been able to replace the Kroll process on an industrial scale (Roux, van der Lingen and Botha, 2019). The most common process used worldwide still remains the Kroll process, which is a very expensive process. Thus, if the Peruke process or CSIR could be successfully commercialised, these cheaper alternatives could be of great benefit to the South African industry (Durr, 2016).

By considering the various properties of titanium and mapping out the applications of the mineral, it becomes possible to evaluate which sectors in the value chain present the best opportunities for South Africa. The applications and markets for titanium are directly derived from the physical, mechanical and chemical properties of titanium. The titanium market is primarily divided into two segments, namely, the metal industry and the pigment industry. There are various reports regarding each of the markets from which a general trend can be established that the metal industry serves a niche market with more expensive and complex products. In contrast, the pigment industry produces lower complexity products on a larger scale. According to Van Vuuren et al. (2005), the various markets that use titanium metal include aerospace, armour, naval, off-shore oil, architecture, sport and leisure, water desalination, and the chemical industry, the power-generation industry, the automotive industry and the medical industry. The pigment industry uses titanium dioxide for its white colouring properties in primarily paint, plastics, ink and cosmetics.

The use of titanium raw material is approximately split between 95% for titanium dioxide in pigments and 5% for the metal. Although the pigment industry is less complex, it serves a more extensive market worldwide (Department of Mineral Resources, 2011). The metal industry has specialised uses for the metal and due to the high manufacturing costs of the metal only a small portion of the industry can afford to make use of the metal – hence its small market share. At this stage it is not yet clear which sectors would be the most strategic for South Africa to invest in, i.e. which sectors would provide the most national developmental benefit. Thus, there is a need for further analysis of the industry and how countries with rich mineral bases should target downstream investments.

Mineral-producing countries have been attempting to implement policies that either enforce the local processing of downstream activities or give advantages to local processors by offering them lower prices or pushing taxes and levies higher on unprocessed export commodities (Morris, Kaplinsky and Kaplan, 2011; Department of Mineral Resources, 2013b; Humphreys,

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2013; Zhang et al., 2015). Such policies have had adverse effects in some cases because international mining companies might be hesitant to invest in the countries that enact such policies, as the policies might influence the firms' attainable profit at that location in a negative manner (Humphreys, 2013). Therefore, countries with a rich mineral base such as South Africa need to carefully consider the impacts of implementing such policies (Bam and De Bruyne, 2017). The focus of the government should be to ensure the long-term viability of new policies, which can be achieved through well-guided intervention planning. Legislative policies should promote support from governments, operational efficiencies and development of logistical infrastructure (De Bruyne, 2006). In a broader view, South Africa should enable companies to have ease of mind to invest in the South African market, being assured that South Africa supports their successful establishment and profitability. Thus, it would mean having interventions targeting the advancement and fulfilment of factors related to achieving high performance in manufacturing, research and development of the products within the titanium value chain.

The South African government has invested significantly in the titanium industry, as it is deemed important for South Africa's economic growth, according to South Africa's Industrial Policy Action Plan (IPAP) 2017/18 – 2019/20 (Department of Trade and Industry, 2016). The DST's plan for innovation towards a knowledge-based economy is a plan based on the idea of driving the transformation process towards an economy in which the production and application of knowledge can lead towards generating local wealth and benefits for society, such as job creation. The benefit of knowledge spilling over to other closely related local industries or companies could be significant.

1.2. Problem statement

Until the closure of Huntsmen Tioxide, South Africa only capitalised on about 5% of the approximately US$9 billion-dollar pigment industry, in spite of the fact that the country supplied about 20% of the total global raw materials consumed in the titanium industry (Van Vuuren, 2009). Furthermore, South Africa does not contribute or benefit from any significant downstream beneficiation activities of the mineral to produce either titanium metal products or value-added products in the pigment industry. Current research by the Titanium Centre of Competence (TiCoC), hosted by the CSIR and funded by the Department of Science and

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Technology (DST) is developing a suite of complementary technologies to help South Africa add value to its abundant titanium resources.

Economic benefits could be significant for South Africa if a downstream industry were to be created to manufacture titanium-based products. This research focuses on how South Africa can place itself strategically in the titanium global value chain. The critical focus points are to analyse the titanium value chain and find the most strategically fit areas for South Africa to enter into the titanium value chain. Such insertion initiatives should be targeted as strategically as possible to ensure maximum benefit. Once the sectors in the titanium value chain are identified, the next problem is assessing what key factors will influence South Africa's ability to support an industry in the identified sectors. Establishing the most important factors that will attract investors, foreign or domestic, will allow for accurate intervention planning and guidance to develop policies in such a way that key factors that can enable South Africa to become competitive in the identified sectors are promoted. This allows an assessment of the initial difficulty of insertion and targeting specific sectors and what is required of the country to thrive within the country.

1.3. Research aim

The aim of this study is to apply a two-phased holistic analysis framework relating to the case of titanium in South Africa in order to derive key policy recommendations. The first phase constitutes the evaluation of the areas that are of key strategic value in the titanium value chain from a capability theory perspective using the most relevant framework. The second phase entails enriching the analysis from the first phase through a bottom-up process that is based on the key location determinants of activities related to a specific industry. By establishing a more granular understanding of the key factors related to the industry and location being analysed, more comprehensive intervention planning can be achieved and recommendations for key dimensions to focus on provided.

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1.4. Research objectives

The objectives mentioned below have been identified as key steps in completing the research, as each step plays a pivotal role towards completing the research aim of this thesis:

1. Evaluate existing methods for the analysis and selection of key areas of a chosen industry's value chain to target;
2. Evaluate literature that enables the guidance of how to target selected industries;
3. Evaluate the background of the selected industry in terms of:
    a. The value chain structure of the selected industry and current activities within the industry;
    b. The international players that have an impact on the industry; and
    c. The history of the industry in South Africa with regard to production and government initiatives.
4. Apply selected analysis methods to the selected industry to be able to:
    a. Identify the key areas to target;
    b. Evaluate if and how these selected areas could be targeted; and
    c. Refine the selection methodology.
5. Reflect on the results, methodology used, strengths and weaknesses of methods used and implications for government policy; and
6. Recommend an agenda for future work.

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1.5. Research outline

The research outline for this study is shown in Figure 1.1 below. These steps were followed to achieve the research objectives established in Section 1.4.

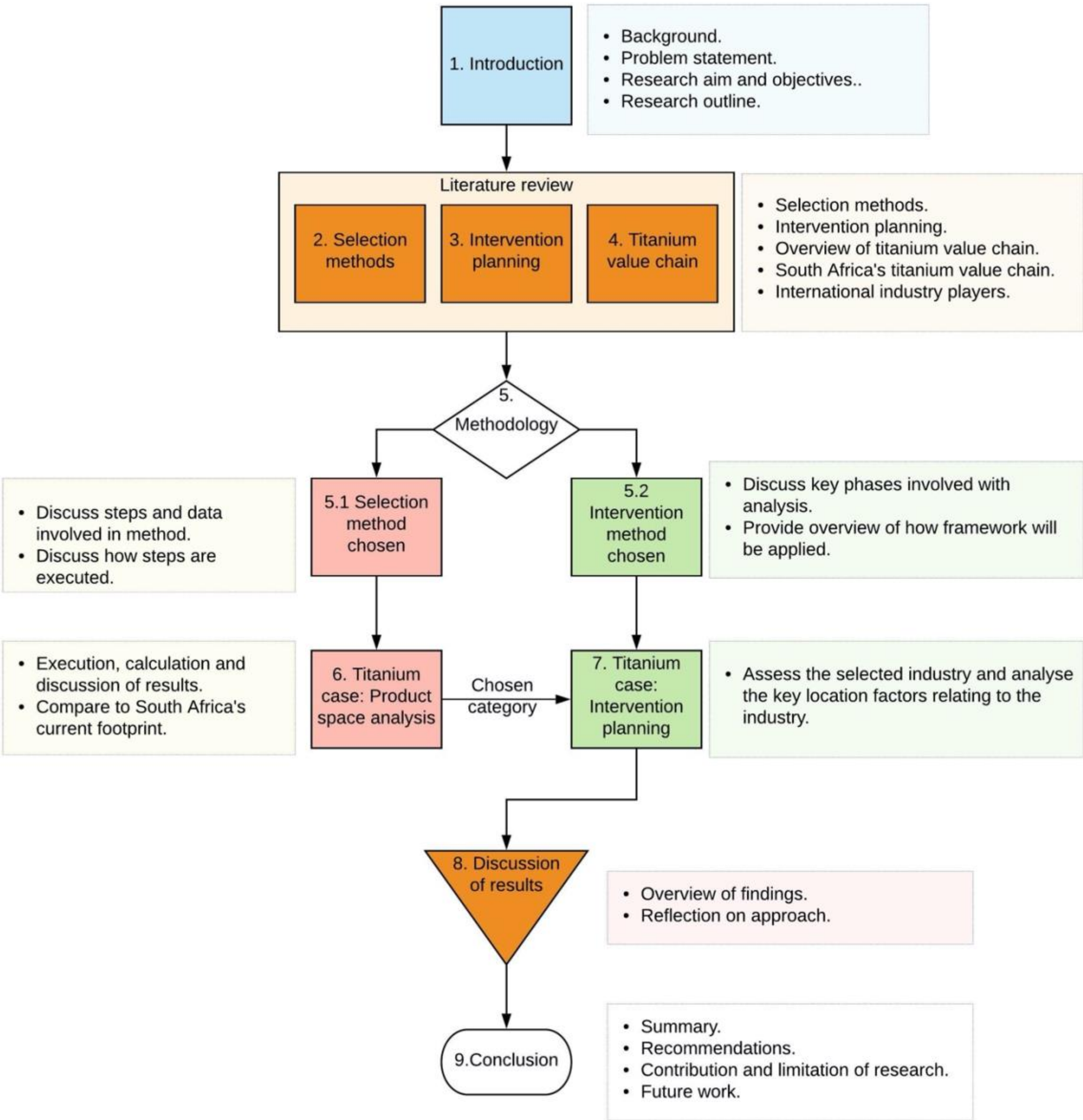

Figure 1.1: Overview of research outline

Chapter 1 focuses on providing the reader an introduction and background regarding the problem that needs to be solved as well as the research outline that is followed during the study.

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Chapters 2, 3 and 4 contain the literature review that evaluates the appropriate methods that can be used for the selection of key areas for a selected industry's value chain. The theoretical background is discussed in the literature review and the execution thereof in Chapters 5 and 6. The literature review next focuses on the importance and role of proper intervention planning and finding a relevant framework allowing the assessment of how best to target the selected industries. The evaluation is aimed at establishing what the key factors, related to the industry are, that should be targeted by the policies. The literature review chapter concludes with the analysis of the selected industry through establishing its value chain, that of South Africa and international markets' position in the industry.

Chapter 5 discusses the in-depth methodology followed in this thesis. First, the selection of a methodology is discussed followed by the intervention planning methodology. This is followed by how these selected methods will be applied to the chosen industry.

Chapters 6 and 7 contain the application and discussion of the selection method's identified areas and the intervention planning methods for assessing the key factors, respectively. The analysis phase of the research comprises of the analysis of the results and identifying the key segments, based solely on the metrics within the selected industry's value chain target. Assessing these segments through the appropriate framework highlights the key factors that South Africa would need to focus on through appropriate interventions. Through successful intervention planning the key factors established are aimed at, allowing South Africa to support the identified industry and allowing a competitive environment. Numerous unknown obstacles are discovered during the assessment of the industries, which leads to evaluating and refining the methodologies and the suggestion to not pursue specific industries based solely on the initially chosen metrics.

Chapter 8 discusses the key findings from the frameworks applied in Chapter 6 and Chapter 7. The limitations of the initial results are discussed by addressing the obstacles that were encountered during the application of the framework used for the intervention planning. The strengths and weaknesses of the methods used are discussed towards the end of the chapter. Finally, Chapter 9 concludes the document through establishing recommendations for future work and the conclusions from the presented research.

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Chapter 2

Literature review – Selection methods

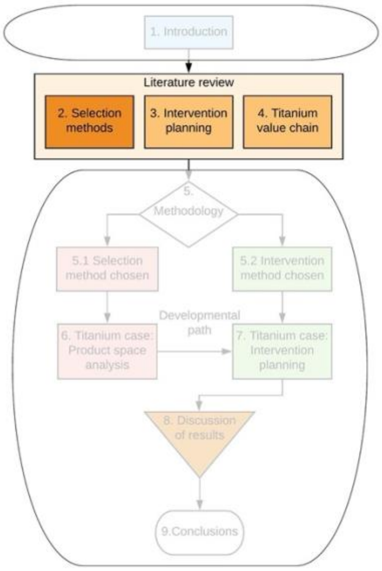

Figure 2.1: Document progress, with focus on Chapter 2 – literature review on selection methods

The purpose of this section is to provide an overview of the general decision-making methods or frameworks that can be used to assess in which new potential industries to invest. The ideal decision method should take into consideration factors such as the country's current capabilities, the economic growth new segments can enable and what other positive (and negative) effects the selected industries can lead to. The literature review for Chapter 2 was guided by searching for frameworks or analysis approaches that are capable of finding solutions that accommodate the factors mentioned above.

The chapter starts with Section 2.1 discussing the significance of choosing the applicable decision-making model. Section 2.2 briefly discusses techniques that can assist in mapping out the respective processes of titanium beneficiation. The focus of the study is on mineral beneficiation, thus, methods available for analysing the stages of mineral processing are important to grasp. The section continues with addressing techniques that have been used previously to evaluate and select the best solution when various alternatives and solutions are available. In Section 2.3 the theoretical foundation for the framework that will be used is

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discussed. As previously mentioned, the application of the framework is discussed later on in Chapter 5.

2.1. Significance of applicable decision model

The difficult choices governments often face include deciding which industries or products to support to improve development. In particular, they need to decide which industries or products will support industrial diversification and economic growth in the country. Countries generally undertake resource-intensive selection processes when they have to select appropriate sectors in which to invest (Du Plessis and Bam, 2018). Governments have shown trends to invest in developing specifically targeted areas that show potential for further development with the aim of growing the country's economy (UNCTAD, 2011b).

Selecting sectors within value chains needs to be done in such a way that the selected profiles align with the government's strategic goals and provide the best outcomes for the given investment (Du Plessis and Bam, 2018). Normally investment decisions involve a great deal of complexity and various different considerations to be taken into account and therefore an iterative, multi-phase feasibility process is applicable. Each alternative is examined until the best option is reached. However, it is no simple task to identify the appropriate sectors to focus on and maximising economic value is not the only consideration. Environmental and social factors have become increasingly important. Policymakers rely on tools and instruments such as indicator frameworks or decision-making models to improve decision-making, all of which have to be done in a timely manner. The goal is to reliably and rapidly identify the most appropriate sectors for investment promotion that would yield the best developmental return on investment (UNCTAD, 2011a).

2.2. Setting the analysis perspective for titanium beneficiation

As this study involves the analysis of mineral processing stages (i.e. beneficiation), it is important to understand and define the various approaches, techniques and models that are available for analysing the production stages of converting raw material into final products as

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well as selecting the best alternative. Thus, the first step, is to identify how the related activities, categories or sectors related to titanium beneficiation can be mapped out (addressed in Section 2.2.1). Once these methods have been identified, the next step is to identify which is the best alternative to pursue, by reviewing different techniques based on relevant indicators (Sections 2.2.2 to 2.2.4 provides an overview of different approaches). As stated in Section 1.1, the goal is to identify the most appropriate sectors to target in a reliable and timely manner.

2.2.1. Mapping out activities, categories or sectors related to titanium beneficiation

The 'Filière' concept, which initially only dealt with local production systems, is primarily used to describe the flow of physical inputs and services in the production system (Kaplinsky and Morris, 2000). The main use for this approach is for mapping out the commodity flows and identifying the main agents and activities involved in the chain, which can be viewed as a physical flow chart of the commodities and transformations. This is a very quantitative approach, analysing the various inputs and outputs, costs and value addition at each stage in the value chain. It is very static in nature and does not account for any dynamics such as growth or decline and knowledge transfers. (Kaplinsky and Morris, 2000). The Filière concepts are generally applied to domestic value chains, stopping at national boundaries.

Commodity chains form a network of labour and production processes working together towards creating a finished commodity (Hopkins and Wallerstein, 1986). All firms involved in the process are accounted for and provide insight into how production, distribution and consumption in different sectors and activities within a commodity chain are influenced by social relations (Drost, Van Wijk and Vellema, 2011). Commodity chains offer new insight into discussing developmental issues such as competition and innovation. This leads into global commodity chains, where, in essence, although globally dispersed, yet linked through a production system, there are dominant firm(s) that influence the overall character of the chains. The global commodity chain framework makes a distinction between two governance types, namely, buyer-driven and producer-driven commodity chains. This allows for understanding all the role players involved and establishing each role.

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A value chain depicts how value is added as the chain of activities continues towards the final product. Thus, the more value companies can add through primary or secondary activities, the higher the margin will be in which they exceed the cost of production (Porter, 1985). Knowing which sectors have the highest return on investment assists strategically in selecting the best sectors or areas to target. The better this is executed; the better the competitive advantage will be over competitors. A global value chain includes activities that are executed at a global level through inter-firm networks. The global value chain analysis methodology consists of four basic dimensions (Gereffi and Korzeniewicz, 1994; Gereffi and Fernandez-Stark, 2011):

1. Input-output structure (that describes the process of transforming raw materials into final products);
2. Geographical analysis of key role players;
3. Governance structure, how the chain is controlled; and
4. Institutional context in which the industry's value chain is embedded.

Global Value Chain (GVC) analysis can provide insight as to how global firms are linked through reviewing the structure and dynamics of the role players. It assesses how countries can upgrade the activities in which they are involved and how this might be constrained by the key actors that play a large role in the global value chain. However, when applying value chain analysis with the purpose of promoting sectors for further development it is important to look at them from various perspectives (FAO, 2013)**.** This is due to the complexity at play when assessing interrelated elements such as domestic and foreign markets, inputs, outputs, production factors, institutions and natural resources (Kaplinsky and Morris, 2000). The following domains are potential perspectives which have to be considered when analyses are carried out (FAO, 2013)**:**

a) Socio-economic context of the value chain;
b) Demand for value chain outputs;
c) Analysis for institutional set-up;
d) Analysis of input and output markets;
e) Functional analysis of the value chain; and
f) Economic analysis of the value chain.

Due to the multiple dimensions embodied, a value chain analysis naturally lends itself to extensions and cross linkages with other complementary analytical approaches, including

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qualitative ones (FAO, 2013)**.** The main purpose of this study is focused on which sectors can best support economic growth and whether/how these sectors could be successfully targeted.

2.2.2. Review of decision support models and tools

In this section an overview is provided of methods that are used to identify the most suitable option from among a number of alternatives, by comparing the expected requirements and consequences of each option. A review performed by Gonzalez et al. (2015) highlighted numerous decision-making techniques available, although the main purpose of their study was to focus on the techniques firms use to analyse scenarios and potential solutions. Their review remains relevant to this study, however, as governments are faced with similar tasks when considering which sectors to select for intervention initiatives. The techniques discussed are deemed appropriate for the aim of this study, as it seeks to weigh numerous sectors against each other to find the optimal sector to target. Articles specifically analysing sectors within value chains are rare, thus, to get an overview of the available techniques for the study the review paper of Gonzalez et al., (2015) was used as a reference. The 38 papers that were reviewed as well as the classification of each methodology are shown in Table A.1 in Appendix A. Table A.1 provides a summary of how the various analytical models are used for different scenarios to solve the problems described in each paper. Reviewing these papers provided greater insight into the various decision support models and tools available to be used in the analysis of the titanium value chain.

It was found that, of the 38 papers reviewed, 14 papers developed and tested optimisation models, 6 papers used simulation and heuristic approaches, 8 used multi-criteria decision analytical approaches, 4 used life cycle assessment-based models and 6 used soft operations research-based techniques as can be seen in Figure 2.2.

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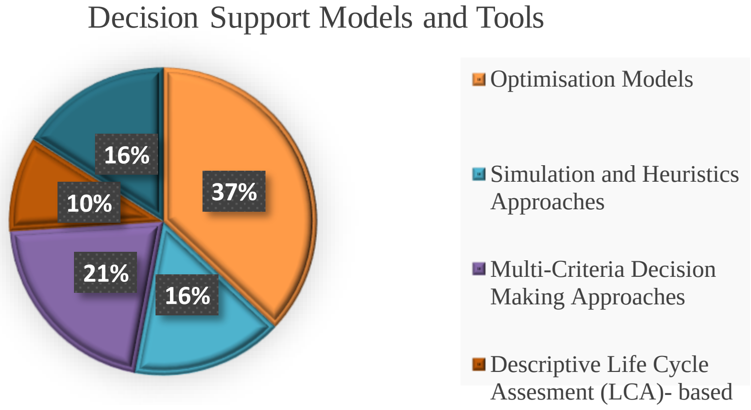

Figure 2.2: Division of decision-making models

Optimisation models – Three separate papers from F. Liu, Xie & Liu (2015); Mota, Gomes, Carvalho & Barbosa-Povoa (2015) and Paraskevas, Kellens, Dewulf & Duflou, (2015) used multi-objective optimisation models as decision-making tools. The problems solved in those problems were very different in nature and required different techniques and solution methodologies for multi-objective optimisation, which is an indication of the adaptability of the models, which can be beneficial towards solving the problem of identifying which segments to promote for investment in the titanium value chain. The fact that they can be used in conjunction with other approaches makes them strong candidates for use in multi-methodological studies. A drawback of using multiple methodologies is that the approach can quickly become very complex and time-consuming. In particular, it can become time-consuming to calculate the optimal results and difficult for managers to interpret and understand the results.

Optimisation models are designed to showcase the best solution given all the constraints and variables that are accurately defined, which can lead to obstacles if such models are selected. This is due to the fact that South Africa is attempting to target segments in a value chain that has numerous unknowns that are still to be discovered and then also has to analyse how these variables affect the country. Thus, the practicality of such models is in question.

Simulation and heuristic approaches – The problems that often need to be addressed can be so complex and bounded by various constraints that practical issues are difficult to address. There are numerous potential constraints that have to be taken into account when deciding to promote certain sectors for beneficiation. The use of simulation and heuristics can allow for issues to be

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considered that otherwise cannot be addressed in optimisation models. Gonzalez et al. (2015) also found that the number of tools available to be used in this scope is greater than those available in optimisation. This is due to the fact that most of the times the solution is not necessarily required to be optimal as "good solutions" for various scenarios for the same problem are sufficient. These tools also showcased integrative capabilities, as the cases they were applied to had different techniques and aspects that had to be incorporated into the tools used. Although the combination of simulation and heuristics improves the understanding of complex problems, it still remains difficult to be able to state what the relatedness is between the country's capabilities and the productive requirements for the new segments. Furthermore, this approach often does not take into account the possibility of trade-offs.

Multi-criteria decision-making approaches – When considering mineral beneficiation decisions that need to be taken, there are numerous dimensions and multiple trade-offs that need to be considered, as each has an effect on the solution. Therefore, the use of multi-criteria decision-making tools seems to be for this study. The benefit of multi-criteria decision-making tools is that they can balance dimensions that are in conflict with each other (Bai & Sarkis, 2010; Chai, Liu, & Ngai, 2013). Some of the studies that are classified in simulation and heuristics can also be classified in this category (Figueira, Greco, & Ehrgott, 2005), but similar to the simulation issue, many multi-criteria models are perceptual and optimisation is not necessarily the end goal.

Descriptive life cycle assessment (LCA)-based models – Life cycle assessment is a more descriptive form of analysis to support decision-making. Why and how certain phenomena happen in a particular domain are the main focus points of descriptive models (Bell, Raiffa and Tversky, 1988). Generally, these models are used to describe past and current performances. However, they can also be integrated with other models. This can potentially be used to assess the trend that industries are moving towards within the titanium value chain and to identify which products industries will target in the future, or the capabilities required from such a product.

Soft operations research-based technique – More often than not, the problems that need to be solved are beyond the traditional mathematical modelling methods of operations research and thus the need for soft operations research exists. These types of models are structured and rigorous but remain non-mathematical, making them useful frameworks for solving ill-defined

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problems. These models are particularly useful for leading decision-making processes where stakeholders with conflicting views and different interests are present (Rosenhead, 1996).

Although all of the above models and tools are very useful in their respective domains, there is still limited insight into selecting industries once they have been mapped out. The next two sections address tools that have already been applied to selecting specific industries.

2.2.3. Sustainable development indicator-based framework

One framework that has attempted to support the improved selection of industries that countries should target to support their development, is based on sustainable development disclosures by large corporates. The framework considers the sustainable development potential of industries. The framework by Du Plessis and Bam (2018) is based on the Global Reporting Initiatives G4 Sustainability Reporting Guidelines (GRIG4) using 18 indicators to compare potential industries in terms of various triple bottom-line considerations. The framework enabled the holistic, transparent and interpretable comparison of industries. However, the framework has limitations towards assessing the fit of such an industry in a local economy, establishing the expected growth trends and the quantification of indirect economic impacts. The heavy reliance on GRIG4 guidelines was also identified as a threat towards the future usability of the framework.

2.2.4. Input-Output Product Space (IO-PS)

Within the product space literature numerous studies focus specifically on selecting industries by using the product space domain as their basis. A study by González et al., (2019) used a multi-criteria analysis of economic complexity transition in emerging economies specifically focusing on Paraguay. Bhorat, Rooney and Steenkamp, (2019) also looked at building economic complexity in Africa, examining structural change through an economic complexity lens. Hartmann, Bezerra and Pinheiro, (2019) and Hausmann and Chauvin, (2015) searched for strategies that can assist with economic diversification and inclusive growth through making use of the product space concept within their respective studies. Another study proving the further value of using the product space for selecting certain products that will be of value

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for a country is by Vardhana Singh, H., Gupta, K., Sudan, R., Singh, (2018) assessing India's potential.

Another method that has been proposed for the identification of a strategic section of a value chain is the input-output product space (IO-PS) approach developed by Bam and De Bruyne (2019). The IO-PS can be used to complement other analyses, such as the sustainable development indicator-based framework mentioned in Section 2.1.2. However, the IO-PS framework does not consider factors outside the product space, such as political, financial, environmental and social factors.

The IO-PS complements traditional analyses in three ways:

i. It provides a detailed lens by allowing a quantitative analysis at product category level. It thus moves past the tier level of the value chain to focus on more specific products where certain complexities that are not visible at the tier level can be discovered;
ii. The IO-PS framework considers policy strategies for a specific mineral value chain whilst simultaneously considering products from other value chains with similar capability requirements; and
iii. It brings quantitative metrics (distance, opportunity gain and complexity – discussed in more detail in Section 2.3.5) to the analysis of the input-output mappings.

The IO-PS allows the sectors being targeted in the value chain to be prioritised according to quantitative metrics which takes into account South Africa's current industry structure, institutional set-up and the current input and output structure. Through combining value chain analysis techniques and selection techniques such as simulation, optimisation and multi-criteria analysis, the IO-PS analysis provides a strong analytical platform. The technique allows numerous activities within the value chain to be analysed in a rapid manner and provides suggestions on activities that can provide long-term development benefits. Generally, most of the studies using the product space literature do not focus on one specific industry or activity except for the IO-PS by Bam, De Bruyne and Schutte, (2020) and because Du Plessis and Bam, (2018) is not ideal for developing countries, the IO-PS was deemed to be the only appropriate solution.

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2.3. Theoretical foundations of the product space methodology

This section seeks to provide more details on the product space's theoretical foundation. This provides the foundation on which the IO-PS methodology is built. The discussion is further contextualised by providing examples from previous studies that have focused on South Africa.

2.3.1. Product space network

The purpose of this analysis is to assess which sectors in the titanium value chain are strategically the best option for South Africa to target. This involves identifying which sectors will offer the most value, require affordable investment and can be manufactured by South Africa. Thus, by looking at segments in the titanium value chain and identifying products similar to what South Africa is currently producing is a viable option. The challenge is in attempting to measure the similarity in the capabilities when comparing different products, as it is not that simple to determine the precise technical and institutional requirements for each product. Such a process would involve collecting an extensive amount of information for each product, leading to high research and analysis-related costs and time requirements. Hence, what Hidalgo et al. (2007) did, was that they used the probability that products will be co-exported as an indication of the similarity between those products, and that in turn provides an indication of how to calculate the proximity of these items. The calculation of proximities allowed Hidalgo et al. (2007) to draw up a network of connecting pairs of products likely to be exported together and this network is called the product space shown in Figure 2.3 below.

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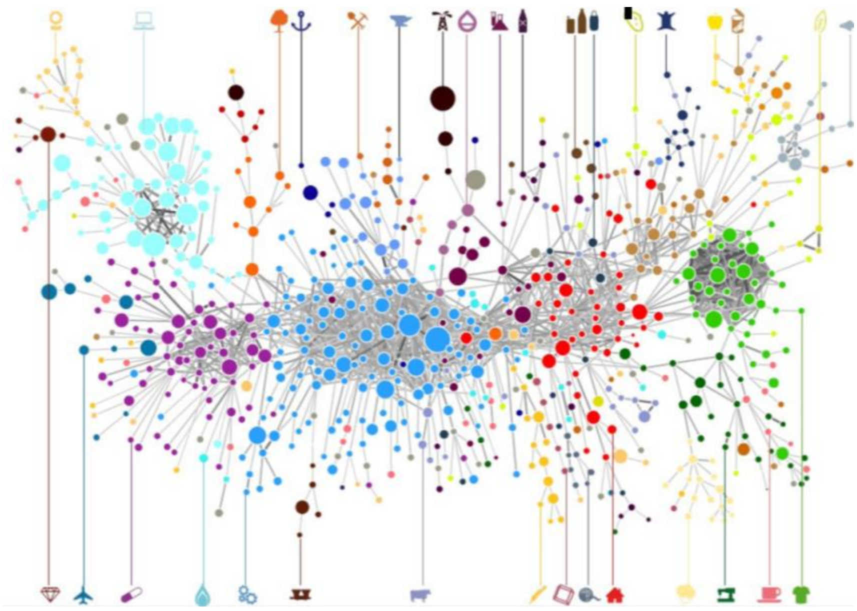

Figure 2.3: Network representation of the product space as presented by (Hausmann and Hidalgo, 2011)

The structure of the product space is important, as it gives an indication of how easy or difficult it is to move between products i.e. to start producing new products. A highly connected product space will therefore make it relatively easy for a country to move between products, as most products are within close proximity to each other, implying they share similar prerequisite requirements (Bahar, Hausmann and Hidalgo, 2014). Countries can either find themselves in the centre of the product space where they are in close proximity to most products or on the periphery of the product space where the distance between products becomes significant.

The following metaphor, used by Hausmann et al., (2014) conveys the concept of product space in a simple manner. Imagine the product space shown above is a forest and each product represents a tree. Trees that are densely packed (e.g. towards the centre of the map in Figure 2.3) usually require similar production related capabilities. However, those that are sparse (e.g. towards the outskirts of the map in Figure 2.3) require different capabilities. So, if countries can be seen as a collection of firms that produce different products, the firms can be represented by monkeys that live in these trees, which means they make a living by exploiting certain products. Each country is different regarding its location in the forest, either towards the centre or on the outskirts, and there are a number of monkeys in this common forest. The development process, adding more complex products, is done by the monkeys inhabiting new trees that are fruitier and more complex (Bahar, Hausmann and Hidalgo, 2014). Therefore, in densely packed areas of the forest it is easier for the monkeys to move around, as most of the current capabilities

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are compatible for developing new products. On the outskirts of the forest where trees are sparsely placed, it is difficult for monkeys to move around. If the product space is concentrated, then products have highly relatable capability requirements and expanding into new products will be easier. In contrast, when countries are on the outskirts the accumulation of capabilities and diversification is difficult (Cimoli, Dosi and E. Stiglitz, 2008).

The methodology developed by C. A. Hidalgo et al. (2007) empirically maps out the ‘product space’ through which structural transformation takes place. It is through this mapping that it is evident that South Africa falls on the periphery (which is discussed in more detail in Section 2.3.4, which seems to have specialised in activities with specific factors that cannot be redeployed to new activities. Hausmann and Klinger (2007) concluded that South Africa has demonstrated little export growth since the 1960s and has fallen behind other developing countries in terms of export sophistications. South Africa has not been able to change its export basket mix by moving to new, more sophisticated production activities.

2.3.2. Moving through the product space

Although there are challenges and barriers preventing countries from moving across to whichever activities they wish, Hausmann & Klinger (2009) and C. A. Hidalgo et al. (2007) investigated the determinates of the evolution of sophistication and found that the challenges and barriers have lower impact when countries pursue “nearby” products. This statement is based on the idea that every product requires highly specific inputs such as knowledge, physical assets, intermediate inputs, labour training requirements, infrastructure needs, property rights, regulatory requirements or other public goods (Hidalgo et al., 2007). Established industries would have experienced and fixed the various pitfalls making it simpler for new entrants to enter the industry by ensuring the above-mentioned requirements are already in place. This cannot be said when firms venture to new products, as they need to start from scratch working towards obtaining all the required inputs. Thus, moving to “closer” products implies chasing activities that require mostly similar input and production capabilities; hence the country can adapt more easily. Products closer to each other, with higher proximity, have a higher probability of being co-exported together. It can thus be assumed that they likely require similar inputs or production requirements (Hausmann and Klinger, 2008b).

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Moving through the product space involves dealing with the chicken-and-egg problem, which affects structural transformation. For the private sector there are not necessarily always enough incentives for them to invest in the process of accumulating the capabilities required by yet non-existent activities to start production in those sectors (Hausmann and Klinger, 2008b). Therefore, we see new activities being developed "close" to those that are already being developed. Yet, South Africa needs to take bigger leaps to move away from the periphery of the product space. This implies that South Africa will move further away from products in which they have a comparative advantage, thus skills and capabilities will have to be improved and will require larger initial investments with the aim of opening doors for future opportunities once new capabilities are established. Many requisite capabilities are non-tradeable such as specific skills, infrastructure and regulations that are mostly public inputs provided by the government. With the South African Government's interest in titanium it might be possible to attain these inputs to help the private sector to overcome coordination failures, given the current interest to develop this industry. One of the challenges is to provide enough information for both the government and private sector regarding which new activities are feasible and will provide the best opportunity gain for the future.

2.3.3. Increasing productive capabilities to support economic growth

Through various research papers it is shown that economic growth tends to co-occur with increased diversification of a country's productive structure, except for the occasional commodity boom (Llamosas et al., 2018). Therefore, countries are more likely to target development of a more diversified and complex productive structure, as those structures lean towards achieving higher levels of economic and social development than countries that prefer high export levels in terms of raw materials (C. Hidalgo and Hausmann, 2009; Hausmann et al., 2014). It is therefore worth pursuing development opportunities that will upgrade and diversify a country's productive structure (C. Hidalgo and Hausmann, 2009; Felipe, 2015). The problem with diversification originates with governments not knowing which productive structures to target first. Lower- to middle-income countries such as South Africa often have very limited resources to invest, hence the importance of astutely choosing which sectors to invest in for the best return in economic and social development.

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Hidalgo and Hausmann (2009) argue that a country's productive structure is defined by the availability of local unique inputs and outputs such as skills and infrastructure, which can be referred to as capabilities, similar to the domains mentioned in Section 2.2.1. These capabilities are the building blocks of the productive structure that consists of tangible asset inputs such as infrastructure and land, as well as intangible assets such as institutions, norms, skills and knowledge. The product space theory and the methodology can be applied in the mineral beneficiation industry to assess how and which of the more sophisticated products can be introduced to a country's current productive basket.

2.3.4. Alignment with current productive structure

The product space is one of the concepts that was integrated with the multi-criteria decision-making approach in particular with the analytical hierarchy process (AHP) in Section 2.2.2. The concept behind product space analysis is still relatively new, but very applicable to a country's productive structure and economic growth, hence making it an attractive potential-analysis approach that can be used. Although the AHP process is capable of analysing a variety of factors that are relevant to policymaking and more specifically selecting industries to target, analysing these factors concurrently is beyond the scope of this research. The main focus remains on national economic growth.

The product space is a network, as can be seen in Figure 2.4 below, that formalises the relatedness of products being traded globally. This innovative approach leads to the network structure that connects products, based on the probability that a country exports those products in tandem. There have been previous studies conducted on Africa before by Hausmann and Klinger (2008a) where the message for developing countries is to target products that require similar capabilities and to systematically develop new productive capabilities that allow the targeting of higher valued goods (C. Hidalgo and Hausmann, 2009). This approach assumes that the similarities in capability requirements of the products can be derived through the probability that two products will be co-exported together (Hausmann et al., 2014).

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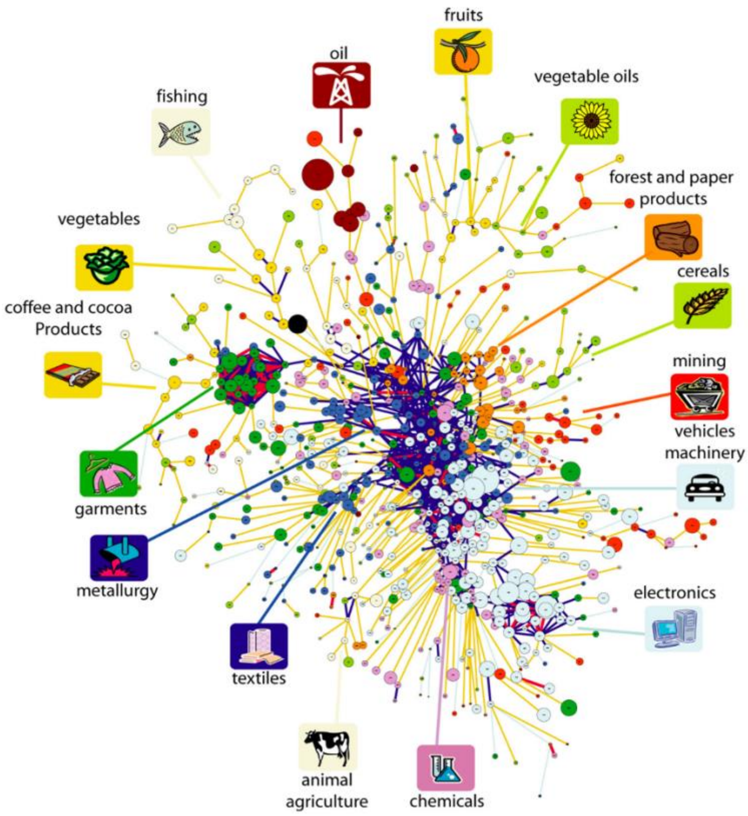

Figure 2.4: Network representation of the product space as presented by (Hidalgo et al., 2007)

The nodes represent the products with the sizes proportional to the volumes of the products present in world trade. The colours of the nodes correspond to the classification of the products. The links between the nodes are the distances between the products that are determined by the proximity. The colours of the links connecting a pair of nodes represent the degree of similarity of the capabilities needed to manufacture the two products.

Through the input-output mapping of the titanium value chain, the IO-PS can assess where products in a value chain are placed relative to South Africa's current productive structure on the product space network. It allows the possibility of systematically analysing the products that are both the closest to South Africa's current productive structure and which products are the closest to other strategic products in the product space, which can support the future development of these products and, hence, economic growth. Thus, using the product space concept could support the identification of potentially strategic segments of the titanium value chain, as this analysis will allow the identification of the products in the titanium value chain that will promote the best economic growth opportunities whilst being the most attainable given South Africa's current production capabilities.

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2.3.5. Product space concepts and metrics

The following calculations and key performance indicators for different sectors are used in IO-PS analyses. The methodology for the analysis is based on the framework of Bam and De Bruyne, (2019) in their article, Improving Industrial Policy Intervention: The Case of Steel in South Africa. As mentioned before, the concept of the product space was first introduced by C. A. Hidalgo et al. (2007) and is pinned around the concepts of proximity and revealed comparative advantage (RCA).

2.3.5.1. Revealed comparative advantage

Although there are various methods for calculating a country's RCA, most of the work, including that of C. A. Hidalgo et al. (2007) is based on the Balassa index introduced by Béla Balassa and Mark Nolad (1965). According to this definition, the RCA compares the value of the export of a product, i, from country c as a portion of the total exports of that country, to the global value of the export of the product, i, as a portion of total world exports. This is formally stated by (Hidalgo et al., 2007) as:

$$RCA_{c,i} = \frac{x(c,i)}{\sum_i x(c,i)} \Bigg/ \frac{\sum_c x(c,i)}{\sum_{c,i} x(c,i)} \qquad (1)$$

Using the formulation of RCA above, (Hidalgo et al., 2007) define a country, c, to have an advantage when the RCA is equal or greater than 1 and no advantage when the RCA is lower than 1. Thus, South Africa would target sectors for which it does not have an RCA as of yet.

2.3.5.2. Proximity

Using the information from above that, when a country is considered to have an RCA in product i, RCA_{xi} is assigned a value of 1 and when it is considered not to have an RCA in product i, a value of 0 is assigned. Using this binary RCA value, it is possible to define the concept of proximity as:

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$$\phi_{ij} = min\{P(RCA_{xi}|RCA_{xj}), P(RCA_{xj}|RCA_{xi})\} \quad (2)$$

In the formulation it is seen that the proximity between two products (i and j) is a measure of the probability that, if a country has an RCA for product, i, it will also have an RCA for product, j, or the opposite is also applicable, whichever is the minimum. Thus, the proximity will be equal to 1 if all the countries that produce product, i, also produce product, j (and vice versa), and 0 if no country produces the combination of products, i and j.

Hidalgo et al. (2007) used these proximity values to calculate and plot the maximum spanning tree of proximities and by superimposing the links between all the products, they managed to visualise the product space. Refer to Figure 2.3 for a visual reference. The network shows that certain products fall on the periphery and others more towards the core. According to the capability theory, products in the periphery require capabilities that are not compatible with many other products, (C. Hidalgo and Hausmann, 2009).

2.3.5.3. Distance

Once the product space is visualised, the next step is to find the position of a country in the product space relative to the products for which the country currently does not have an RCA larger than 1. The following equation adapted from Hidalgo et al. (2007) is used to calculate the distance to some product, j, for which country, c, does not yet have an RCA of larger than 1.

$$\Delta_j^c = \frac{\sum_i (1-x_i)\emptyset_{ij}}{\sum_i \emptyset_{ij}} \ (for\ all\ i\ \neq j) \quad (3)$$

According to Hidalgo et al. (2007), if the distance to any product, j, is large, it is most likely to be more difficult for a country to obtain an RCA for that product compared to another product with a smaller distance. This implies that, if South Africa is to target a larger distance, potentially reaching more complex products, it might require higher initial investment costs.

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2.3.5.4. Product complexity index and economic complexity index

C. A. Hidalgo and Hausmann, (2009) introduced two other important metrics, product complexity index (PCI) and country economic complexity index (ECI), which are calculated iteratively through the method of reflections. The method is endogenous in the form that it corrects for population size and is able to predict economic growth (C. A. Hidalgo and Hausmann, 2009). The method calculates the complexity of a product by considering the average complexity of the countries that produce the product and calculating the complexity of a country by considering the average complexity of the products it produces. Thus, this method can be considered useful when trying to identify products capable of supporting economic growth (Hausmann and Klinger, 2006, 2009; Felipe et al., 2010). Thus, countries should attempt targeting more complex products as they tend to support economic growth. Following Bam and De Bruyne (2019), in this study the original metrics by Ricardo Hausmann & César A. Hidalgo, (2010) will be used, as it is the most established metric in the literature as well as robust and near optimal as confirmed in other studies.

2.3.5.5. Opportunity value and opportunity gain

The last of the metrics that are considered are opportunity value (OV) and opportunity gain (OG) that are described in Hausmann & Hidalgo (2011) as important metrics for evaluating the strategic importance of development opportunities. These metrics are key indicators towards the potential economic growth that certain products can offer. Referring to the work of Hausmann & Klinger (2006) these metrics, OV and OG, are refinements and contributions to the open forest. A high opportunity value means that the country is within near proximity to a large number of products with high complexity. When referring to opportunity value for a country, c, it describes the sum (for all opportunities j) of the product of the density to each opportunity[ii] j – where density[iii] refers to the sum of proximities of all existing products to an opportunity divided by the sum of all proximities to the opportunity scaled by the complexity of all these opportunities. This is mathematically described as:

$$OV_c = \sum_j \omega_j^c PCI_j \ where \ \omega_j^c = \frac{\sum_i x_i \emptyset_{ij}}{\sum_i \emptyset_{ij}} \ (for \ all \ i \neq j) \qquad (4)$$

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In the case where a country attains an RCA for a specific product in which no RCA exists as of yet, opportunity gain, indicates how much that attainment will contribute towards the country's opportunity value. Opportunity gain for a given product, j, is the change in the opportunity value for a country, c, if it would acquire an RCA for product, j, for which it does not yet have an RCA.

2.4. Chapter summary

In this chapter key analysis techniques were identified that can be used to analyse the various stages involved in the beneficiation of minerals such as titanium. Techniques for assessing alternatives against each other in an attempt to find the optimal answer were also reviewed. Although it is difficult to find the decision-making method that will assess all the domains as mentioned in Section 2.2.1, a decision model that could provide strategic insights towards assessing the economic contributions and growing South Africa's productive structure was found to be the IO-PS. The IO-PS is a useful method to use, as it allows the value chain to be mapped out and evaluated. The analysis enables assessing optimal solutions considering different attributes, such as RCA, distance, opportunity gain and economic complexity. There are, however, numerous unknowns that can have potential implications that are unaccounted for when optimisation is being applied. The IO-PS enables the establishment of different strategies based on trade-offs between short-term and long-term agendas. Short-term implies targeting high complexity products for more immediate rewards, whilst long-term targets are products based on opportunities that can be gained in the future. Thus, the chapter concluded by discussing the various aspects of the IO-PS analysis, how the method is applicable to South Africa and what the key performance indicators are which can be used during the analysis. The application of the IO-PS for this project is discussed in more detail in Chapter 5.

Despite the benefits of using the IO-PS, the method has various shortcomings. Most importantly, it is a heuristic approach that estimates the difficulty of acquiring a particular industry. Yet it does not indicate how the particular industry could be attained or even guarantee that an industry is at all attainable – irrespective of distance. Hence, any IO-PS analysis must be followed by a more bottom-up analysis of the identified strategic industries in order to ensure that the industry would indeed be viable to target and identify how the

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industry could potentially best be targeted. The following chapter thus focuses on methods for identifying the key requirements for successfully supporting an industry.

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Chapter 3

Literature review – Intervention planning

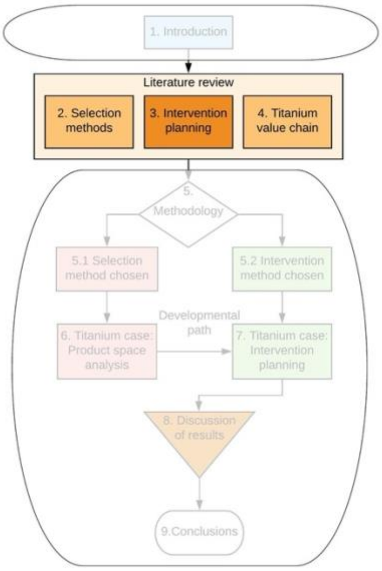

Figure 3.1: Document progress, with focus on Chapter 3 – literature review on intervention planning

The purpose of intervention planning is to evaluate the key factors that can affect the success of particular value chain segments within a country. The necessity to identify these various factors is critical, as this will help uncover where South Africa's strengths and weaknesses lie when targeting the specific segments of the titanium value chain identified using the chosen sectoral selection approach. Such an analysis will support the prioritisation and adaptation of policies and regulations. Through precise intervention planning the recommended policy adaptations could support local and foreign investors to operate successfully in the strategically identified sectors of the titanium value chain. As stated in the selection stage, there are numerous unknowns that cannot be included in the initial analysis. Addressing these unknowns is the purpose of this second stage of analysis.

In this section the first phases from Section 3.1 establish the narrative of a government's interest in using policies to enhance beneficiation initiatives and how the policies can improve the local development of raw material-using industries. Section 3.2 establishes the idea that a location

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is affected by various inherited factors that have to be considered, as policies need to take into account these location-inherited factors. Section 3.3 shifts the narrative towards assessment factors specifically related to the performance potential of an industry being supported in a specific location. Finally, Section 3.4 provides an in-depth description of the framework chosen to guide the intervention planning.

3.1. Mineral beneficiation and government policies

For some time, it has been argued that mineral-producing countries such as South Africa, have the potential to industrialise and diversify their economies by processing mineral ores towards final products (United Nations, 1984). Mineral-producing countries have been attempting to implement policies that either enforce the local processing of downstream activities or provide advantages to local processors through offering them lower prices or escalating taxes and levies on unprocessed export commodities (Morris, Kaplinsky and Kaplan, 2011; Department of Mineral Resources, 2013b; Humphreys, 2013; Zhang et al., 2015). Such policies can have a cost (and sometimes a significant cost) to the government’s fiscus when they are based on promoting downstream activities through either direct or indirect support. Otherwise, there is a risk of these policies having a negative impact on the upstream part of the value chain if they place the burden of beneficiation on the upstream producers. This is because it would inhibit them from selling of their extracted products to the most profitable international markets through restrictions such as quotas or taxes. A by-product of shifting the burden to upstream producers might be less investment in the upstream part of the value chain, as attainable profits decrease (Humphreys, 2013). Therefore, countries such as South Africa, when targeting the titanium industry, need to carefully consider the impacts of implementing policies that aim to support particular value chain segments and make sure that only viable downstream industries are supported (Bam and De Bruyne, 2017).

Most of the studies that have previously investigated downstream mineral processing are based on linkage theory, initially pioneered by Hirschman (1981). More recent work regarding linkage theory has been done by Morris, Kaplinsky, & Kaplan, (2012) who deal with ensuring that a mine or local processing operation keeps on contributing to the local economy. Linkage theory is useful in establishing the current impact of an industry, but fails to suggest which industries should be promoted (Bam and De Bruyne, 2017) and how these industries, once

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selected, should be promoted. The literature on global value chains and global production networks (pioneered by authors such as Gereffi, Humphrey & Sturgeon, (2005); Gereffi & Korzeniewicz, (1994) and Yeung, Henderson, Dicken, Hess & Coe, (2002)) have more recently also been applied to the study of the mining industry. This addition adds more insight into where firms might have the upper hand due to limited competition and how value is distributed within the value chain, given the power dynamics that exist within the value chain (Morris, Kaplinsky and Kaplan, 2011). Yet, it still offers little insight, once the targeted industries are selected, as to what the key factors are that could support the economic activity and address the viability of committing to such activities (Bam and De Bruyne, 2017). A more in-depth understanding of the exact location determinants is required to provide solid policy recommendations and to understand the bigger picture, more than a descriptive understanding of current relations within the value chain.

3.2. Factors to determine the 'appropriate industrial policy' (AIP)

There are factors related to a country that cannot be changed (e.g. geographical location). Perhaps over time, incremental changes can occur for some factors (e.g. education level of the population), but for other factors the country has to make the best of the cards it has been dealt. When targeting economic growth there are some factors or limitations related to South Africa that need to be taken into account to ensure the new policies take these into consideration.

In the more general field of policy research, recent attention has shifted towards ensuring that an appropriate industrial policy (AIP) is selected for peripheral and 'potentially catching-up' (PCU) economies (Landesmann and Stöllinger, 2018). Although the specific paper targets European countries, it still highlights important factors surrounding policy interventions that have to be accounted for. The shift in global trade shares is caused by impressive development processes in some emerging economies. International production networks (IPN) are also breaking down the barriers between regional and global trade, implying that the location for manufacturing activities is not dependent on the nationality of the head offices, but on locational factors relating to manufacturing, research and development as discussed later in Section 3.4. There are consistent changes in countries' positions in global value chains as a result of the upgrading of technological and human capital. These are all factors leading to the

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global economy experiencing structural changes. Thus, Landesmann & Stöllinger (2018) attempted to create a type of 'appropriate industrial policy' dependent on certain characteristics of an economy that can differ from country to country. Countries should be assessed individually against each characteristic. A thorough description of each characteristic is given below, giving a better context of how each characteristic impacts the 'appropriateness' of policy on the country.

Level of technological development – Aghion & Griffith (2008) pointed out that countries should have different policies depending on how close they are to the technology frontier. The closer a country is to the technology frontier, the more it has to rely on its own capacity to develop new inventions and innovations. The purpose of industrial policy instruments should be to establish an effective R&D sector that ensures and promotes efficient collaboration between business and government and will lead to knowledge spilling over into smaller publicly financed projects and companies. Countries further away from the technology frontier should focus on exploiting the 'advantage of backwardness' (Gerschenkron, 1962). This essentially implies that the country should aim to facilitate easy 'technology transfers' and adapt the imported technology accordingly, to match the country's development level. Thus, the country should focus on its 'absorptive capacity' for new technologies that are required. This is an important characteristic for South Africa, as there are currently world-class research centres and universities involved in projects that are developing new technologies, especially in the manufacturing of titanium. Yet, progress can be slow compared with new technologies available in other countries. Thus, South Africa should find the balance between developing and importing new technologies as this will be essential to establishing a local titanium industry.

Size of economy matters – Small economies are more susceptible to changes in international markets and more dependent on those markets to do well. There are a number of reasons for this namely:

- Small economies have less control of capital in- and outflows; even under flexible exchange rates the manoeuvrability of a monetary policy is limited. This is applicable to South Africa's exchange rate, as the country is very volatile towards international changes; and

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- International investors have preferential consideration for involving small domestic countries, either as an export platform or to form part of a production network including numerous other countries as well.

From a demand side the country must be well integrated into markets beyond its borders, as foreign direct investment and export activity involve high fixed costs. Low regional costs and good transport and infrastructure will be important to make small countries more attractive.

Raw-material endowment – A country's dependence on raw materials should be diminished and this can be done in a number of ways (van der Ploeg, 2011):

- Political economy: Prevent high concentration of ownership in the raw-material sector, as this generally leads to unhealthy dynamics leading to potential state capture. This is a threat for South Africa, as the raw-materials sector forms a big part of the economy and allows large parts to be owned by individuals driven by political wealth, which is dangerous;
- Build up 'endowments' and 'assets' that will allow the opportunity for the country to diversify its economy further than the raw-material base. Building knowledge and human capital that could help transfer dependence towards multiple fronts and not only the raw-material base, which is why the sectors targeted within the titanium value chain should aim at growing the national economy;
- Use the raw-material base to explore other segments of the value chain, such as processing and other higher-valued goods; and
- In case of 'exhaustible resources' develop policies that moderate the exploitation of the resources and simultaneously look towards other tradeable sectors, potentially new sectors based on the knowledge and technology imported from products previously developed.

Geographic factors – Relate to a country's geographical location that is locked and cannot be changed, yet, there are measures countries can take to counter the locational issues. The use of technology in transport and communication is streamlined and very well developed in today's world with a diverse range of solitions available to overcome obastacles, for example, target areas where transport takes place 'virtually'. This has a major impact on South Africa, as all international markets and developed countries are only in reach through flights or shipments.

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Institutional quality – Countries at different economic levels generally have different levels of maturity in the quality of their educational and other institutions. Policies have to be developed accordingly. For example, in developing countries, minimum wages are very low and civil servants will be more prone to accept bribes in some cases. Other issues are that the local authorities in charge of driving and enforcing the policies are inconsistent in quality (effectiveness, legal reliability, transparency in project vetting and approvals) and this can lead to unrest. The better these qualities are, the better services can be provided by local manufacturers in South Africa.

The authors Landesmann & Stöllinger (2018), created a matrix, as shown in Appendix B.1, Table B.1, highlighting the main aspects related to South Africa and the five areas of 'appropriate industrial policy'. The intention was to show that policies should be adjusted according to country-specific circumstances. The above discussed characteristics will be used to guide the recommendations on the interventions ensuring they are "appropriate" towards South Africa.

3.3. Location-centric-related factors

Chapter 2 discussed how to identify the strategic value of certain product categories within the titanium value chain, based on the concepts and work of Hausmann and Klinger, 2008; Bam and De Bruyne, 2017; and Du Plessis and Bam, 2019. The challenge, however, remains to identify how these sectors can be supported in South Africa. Bam and De Bruyne (2017) argued that there is a need for a framework to identify whether certain industries can be supported by a specific country or how they can be supported within that country. Appendix B.2 to Appendix B.4 give a broad overview of the various factors that affect locational and supplier selection. In some cases, merely assessing these factors is not enough and has to be assessed in conjunction with other factors and dynamics such as market-related dynamics. The correct framework can prevent governments from supporting failing industries at great social and economic cost. Thus, from an intervention planning perspective, a holistic framework will assist in establishing the key factors affecting a location's ability to support an industry. Thus, factors that are deemed important by the industry have to be taken into account as well as the location's potential performance attainable.

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Though many fields discuss the location of economic activity, the use of a holistic framework describing the factors affecting the location of economic activity would be more insightful. Such a framework was developed by Bam, De Bruyne & Schutte (2020) through a structured literature review identifying the main fields of literature addressing location issues. The framework was developed for improved location decisions by firms and to assist governments with making developmental policy decisions with the purpose of successfully attracting more foreign direct investment. For this study local firms were included in the analysis. During their exploratory literature review, Bam, De Bruyne and Schutte (2020) identified six fields of literature that are of importance with respect to addressing location determinants in a more holistic view. The identified fields are general economics, economic geography, general management literature, operations (and production management) literature, innovation and development literature. This allowed the conceptualisation of the interaction between demand (the market) and supply (the location). This conceptualisation is completed by means of four phases of analysis. Within each phase the key determinants, very similar to those discussed in Appendix B.2 to Appendix B.4, are highlighted related to the location analysis.

The intervention planning is aimed at identifying how key factors affect the location's ability to support an industry and through applying the framework the key factors can be identified. The assessment of activities at a granular level provides decision-makers with the key factors specifically affecting those activities (related to a specific industry) related to a certain location. This allows the prioritisation of the key location factors related to the industry and the intervention planning to be executed as thoroughly as possible. It also allows the determination of the extent to which the government can provide assistance that will lead to firms being successful in the country. The location-centric framework was developed for the purpose of assessing the above-mentioned factors, although the framework has not yet been tested in any industry or country. Thus, this study would be the first to apply the framework, allowing both the evaluation of the potential of the framework for assessing the industry and location and the framework's compatibility to be used in conjunction with the IO-PS.

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3.4. Framework used to guide the intervention planning

The framework used to guide the intervention planning is a location-centric framework as discussed in Section 3.3. The framework's purpose is to act as a guideline for systematically evaluating the key factors for supporting the identified sectors within the titanium industry at a specific location. The framework is deemed fit as it enables thoroughly assessing the specific market requirements, the related location implications in meeting these requirements and the interaction moderators from the location. Thus, knowing whether a specific market can be served competitively from South Africa will be valuable in the sense that it can prevent risky investments or allow for more accurate planning. The intervention plan is aimed at guiding South Africa towards prioritising the key factors that the interventions should be targeting. The adjustments necessary for South Africa's current beneficiation and intervention policies in the related industries can be identified and key recommendations can be provided.

Section 3.4.1 provides the narrative for applying the specific framework and what the aim of the framework is. This is followed by Section 3.4.2 which discusses the dynamics from both the demand and supply side which have to be taken into account as well the various phases involved in the framework. Lastly, Section 3.4.3 provides insights as to how the framework will be applied during this study.

3.4.1. Location-centric analysis framework

The framework proposed by Bam et al. (2019) is location-centric, implying that a specific location's performance is measured in terms of the location's capability of supporting a specific activity aimed at a specific market. The framework will give companies and policymakers greater insight into understanding what factors affect a location's ability to attract and support particular economic activities. It also allows for comparison between different alternatives. Although the focus for this study remains on the identified segments within the titanium value chain and South Africa, the framework allows for various locations and segments to be analysed simultaneously. In the case of this study, the framework will allow for assessing the key factors from the market's perspective as well as the location's perspective, indicating the

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relationship between supply and demand. The following Section 3.4.2 provides a detailed overview of the framework as developed by Bam, De Bruyne and Schutte, 2020.

3.4.2. Demand (market) and supply (location)

From a demand perspective, the location of the activities is chosen in such a way that the company has the ability to perform certain activities effectively enough to meet the demand of the customers domestically or globally. This can be achieved through the host country, in this case South Africa, establishing a favourable business environment in which organisations can conduct business. The framework compares different locations based on a company's ability to achieve a certain level of performance for specific activities and meet the demand from those locations, although the focus of this study remains on South Africa's ability to serve the titanium-related industries. This relationship between market requirements and location performance is illustrated in Figure 3.2. Each market has its own unique requirements. The customers in each segment will have a particular utility function and demand curve that determines which and what quantity of competing outputs they will consume. The importance of each performance dimension within the utility function might be different for alternative markets.

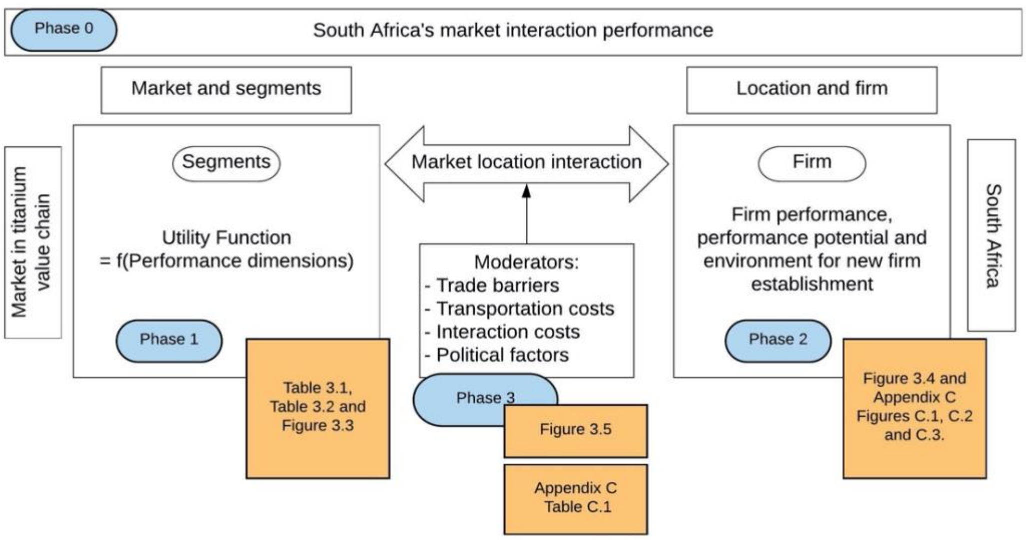

Figure 3.2: Adapted dynamic interaction between locational demand and supply source (Bam, De Bruyne and Schutte, 2020)

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The utility function consists of numerous performance dimensions, which are determined by and dependent on the type of industry. In manufacturing, for example, such a utility function might potentially have costs, quality, responsiveness and lead time that correlate very closely to those mentioned in Appendix B.3. Thus firms, multinational firms in this case, must weigh the different attainable performance levels at each location. Performance levels at each location will also be different, as the levels are moderated by various interaction costs with the markets. Thus, if South Africa can enable high performance levels, firms will be attracted towards investing in South Africa. Each location has a different environment; hence the establishment of new firms is also influenced by factors such as access to markets that influence the success of a firm. As time goes by, there are expected changes in market sizes, the utility functions of markets, competing firms and outputs in the market and the varying levels of attainable performance at the locations (Bam, De Bruyne and Schutte, 2020). The phases below first establish the activity being analysed, followed by the market and location analysis and concludes with assessing the interaction moderators between the market and location.

3.4.2.1. Phase 0: Setting unit of analysis

The first step of the evaluation process for analysis of locational determinants of a specific activity, is to establish which activity (or activities) are under evaluation. The authors, Bam et al. (2019) developed the framework in such a way that different firms can apply the framework, but firm-specific factors cause firms to rate the importance of determinants differently depending on the industry. Thus, a clear description of the activity that belongs to that industry and the type of firms that undertake the activity has to be given, as each has factors affecting them. The importance of these factors can differ depending on the industry and location. Clear distinctions are made between manufacturing, research and development-related activities as well.

3.4.2.2. Phase 1: Market analysis (market definition)

Now that the particular activity has been identified, the market for the activity needs to be identified. The particulars such as demand location, market size and market segments need to be specified. The analysis complexity is determined by the number of customers in the market.

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Related market considerations are outlined in Table 3.1 below. The type of firm might also influence the impact of the location determinants, which can be moderated through various industry- and firm-related factors as shown in Table C.1 in Appendix C. This is ideal for intervention planning, as it allows the key factors to focus on to be narrowed down.

Table 3.1: Market-related considerations linked to new firm establishment in focal locations (Bam, De Bruyne and Schutte, 2020)

Subject of analysis	**Market-related considerations**
Manufacturing	Market size competitively accessible from location (considering different market segments).
	Market congruence with current markets.
Research	Sophistication of customers in region.
	Representativeness of local customer requirements of company's market.
Development	Size of market with similar taste to local market.

3.4.2.3. Phase 1: Market analysis (market requirement definition)

Each customer and market segment will have key requirements that need to be met and this phase is about identifying those requirements. To understand how the location can impact the success of an activity, the key requirements demanded from the customers or market's side have to be identified. Performance metrics again vary depending on segment and activity, for instance, manufacturing-related activities' performance on cost, quality, service level, flexibility, lead time, responsiveness and environmental impact will be important depending on the market segment being targeted as shown in Table 3.2 below.

Table 3.2: Performance dimensions for manufacturing, research and development (Bam, De Bruyne and Schutte, 2020)

Segment	**Performance metrics**
Manufacturing	Cost
	Lead time
	Flexibility
	Reliability
	Responsiveness

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	Quality
	Sustainability (social and environmental impact)
Research	Responsiveness to leading customers
	Ability to improve the state of the art
	Protection of IP (firms are protective over resources and knowledge and tranfer of knowledge or potential collaborations will be difficult to achieve)
Development	Responsiveness to local tastes
	Protection of IP

Aligned with the purpose of this study, the primary segment dimension that will be analysed is manufacturing. The performance metrics indicated in Table 3.2 correlate with those discussed in Appendix B.3 and B.4 where more detail regarding each specific metric is given. Static market determinants are shown in Figure 3.3 below, giving respective policy makers or departments within a government a better understanding of the market being targeted.

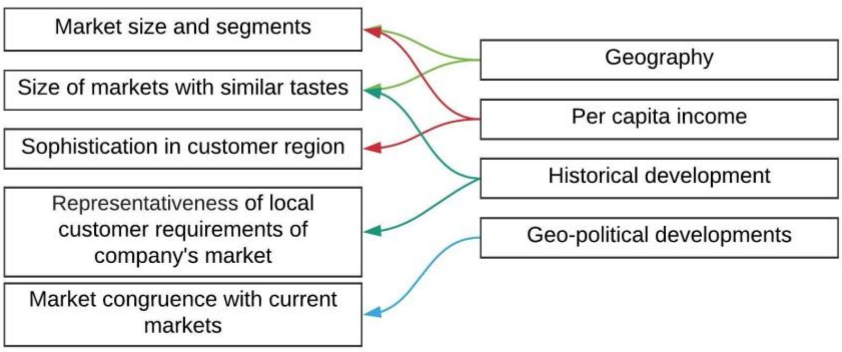

Figure 3.3: Key location determinants that influence market-related considerations (Bam, De Bruyne and Schutte, 2020)

3.4.2.4. Phase 2: Location analysis

During this phase the aim is to determine the achievable performance of the firm for the identified activity. The most important location determinants related to manufacturing (e.g. cost and lead time) are shown in Figure 3.4 below. Factors related to research and development are all shown in Appendix C Figure C.1 and Figure C.2 respectively.

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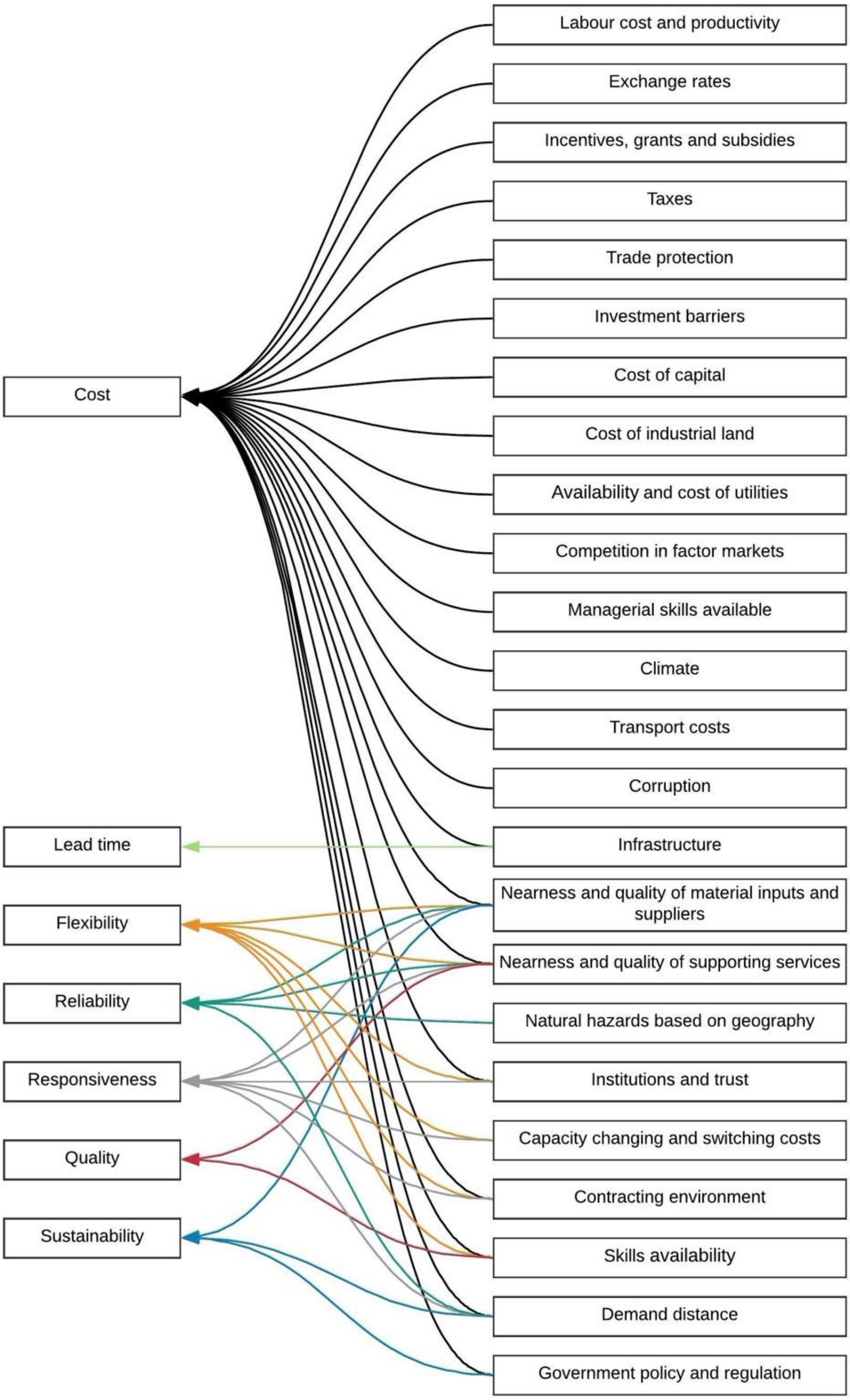

Figure 3.4: Key location determinants that influence manufacturing related performance (Bam, De Bruyne and Schutte, 2020)

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The determinants mentioned above are very similar to those mentioned in Appendix B.2 to B.4, with some omitted and some added. The various determinants will have a different weight depending on the market being served as well as the region, making this framework ideal, as the factors can be identified on a customised front for each market and industry.

3.4.2.5. Phase 3: Interaction and dynamic analysis

Now that the key performance determinants have been established, the different location options available can be assessed against each other based on their abilities to support such performance requirements. Evaluation in terms of the performance that a location can provide that is related to market location interaction moderators has to be assessed as well. The dynamic factors linked to market access and location dynamics are shown in Figure C.3, Figure C.4 and Figure C.5 in Appendix C and market location interaction is shown in Figure 3.5. Projections on the location's ability to support a competitive performance level while allowing for changes in customer requirements and performance determinants as well as discount factors for locational risk and uncertainty can be made accurately, as the dynamics analysis includes these factors. Dynamic considerations such as capability development, learning curve effects and reputational impacts such as sustainability performance can also be taken into account.

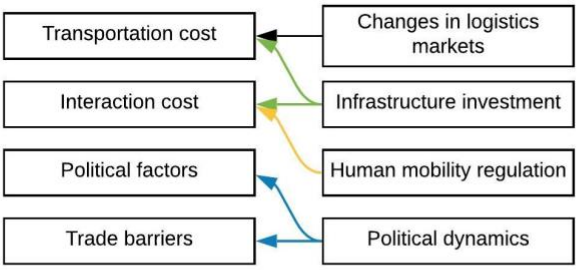

Figure 3.5: Interaction moderator dynamics (Bam, De Bruyne and Schutte, 2020)

Thus, companies can choose the best combination of performance metrics over the planning horizon, keeping risk and uncertainty in check. Over the planning horizon, policymakers and locational planners can try to simulate which performance metrics are likely to underperform and which determinants are responsible. This allows for measures to be put in place to address

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the shortcomings or other determinants that can compensate. Initial intervention planning will initially focus on the static interaction between market and location moderators.

3.4.3. Applying the framework to South Africa

The location-centric analysis framework was developed to be generic, i.e. applicable to any industry or value chain. It thus needs to be adapted before being applied to a particular industry. It has also not been empirically tested, and the potential pitfalls of applying it are not yet established. The framework allows for a systematic evaluation encompassing the multitude of factors that may affect the location of economic activities. The importance of the determinants will vary according to the different markets and industries being targeted. Therefore, depending on the sector or firm a government wants to attract or develop, there will be a need to focus on a particular subset of location determinants.

For this study, the sectors identified in the titanium value chain that are deemed to have the most strategic value for South Africa (based on key IO-PS metrics such as RCA, complexity, opportunity gain and distance), need to be analysed. Consequently, considering the peculiarities of the titanium industry, the structure of the framework and the literature contained in Appendix B.2 to B.4, three key analysis dimensions were defined to guide the industry analysis.

The three key dimensions are:

1. Enablers for winning market share (what product-related factors does the industry value most, related to the customer requirements defined in the framework);
2. Properties specific to industry/firms (impact of industry or firm-related specific moderators affecting the impact of location determinants); and
3. Requirement-location fit (what factors related to the specific activities, manufacturing, research and development identified are important for enabling the performance required for winning market share, and how well does the location being analysed support performance in term of these factors).

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Table 3.3 below provides the three dimensions that will be used to assess the indentified industry in South Africa. The second column provides a brief overview of the factors related to each dimension and where in the study the respective factors have been discussed.

Table 3.3: Key dimensions to be assessed during intervention planning

Dimensions		**Where relevant factors are discussed**
1	Winning market share (requirements)	Section 3.4.2 and Appendix B.3 established the baseline for the assessment of the factors that are important for winning market share. These deal with the Cost of product, Quality of products, Responsiveness to market, and Lead time.
2	Industry and firm properties (moderators)	Various industry and firm-related moderators outlined in Appendix C were investigated. Determining the importance of relevant moderating factors, provides insight regarding the key factors that drive the ability of a location to support the requirements for the industry and relevant firms.
3a	Manufacturing (requirement - location fit)	The factors relevant to manufacturing requirements and location fit are considered in Figure 3.4, Appendix B.3 and Appendix B.4.
3b	Research (requirement - location fit)	The factors relevant to research requirements and location fit are considered in Appendix C.
3c	Developments (requirement - location fit)	The factors relevant to development requirements and location fit are considered in Appendix C.

The first dimension considers which factors between quality, cost of product, lead time or responsiveness to market change are the most important for the market or customers. This is important for winning market share and to establish which areas related to market and location interaction are important during the intervention planning. The dimension establishes what the key end goal should be when the factors in dimension 3 are targeted.

The second dimension analyses the moderators related to the type of firm and industry involved in the activity. It was decided to include this as the second dimension as the impact of these moderators (refer to Appendix C for clear description) can determine the key factors that could influence the performance of South Africa relative to competing locations. The properties assist in determining the key supportive structures that should be focused on to support the industry or firm in South Africa.

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The third dimension, also the biggest dimension, assesses which of the key market- and location-related factors are the most important. It narrows down which factors the market deems most important for the industry, and then the subsequent location factors linked to each can be assessed.

The intervention planning should ensure that the most important factors related to each dimension are prioritised accordingly so that precise recommendations can be provided. Once these key factors are determined, South Africa's potential performance and shortfalls are assessed for supporting the industry. Through assessing both market and location factors in detail, the compatibility of South Africa and the initial selection of the industries can be reviewed.

3.5 Chapter Summary

The chapter initially provides an overview of what drives governments towards establishing mineral beneficiation policies, which are found to be primarily driven by the need to create more value out of the natural mineral base. The chapter continued with a discussion on the fact that there are inherited factors for countries that affect the location ability of downstream processing (related to the value chain), although governments can counter these factors with interventions and recommendations. The key insights obtained were that there are key characteristics that have to be considered when recommending interventions. These characteristics ensure that the policies are appropriate towards a country's development stage related to key areas. It was discovered that the strategic advantage of selecting the correct supplier or offshoring location is significant and led to the succeeding sections. This section focused specifically on assessing what the key factors are that organisations are interested in when evaluating alternative suppliers or offshoring locations. The location-centric framework was deemed most fit for the study, as the framework guides the systematic evaluation and prioritisation of factors related from both the supply and demand perspectives. The chapter concluded with an in-depth discussion around the specific assessment technique that will be used. The location-centric framework is fit to be used as it enables the assessment of the factors discussed in Section 3.4 and provides analysis of the interaction moderators between the market and location. However, the framework needs to be adapted for a particular case. A proposed adaptation for the purposes of this study is presented in Section 3.4.3.

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Chapter 4

Literature review – Titanium value chain

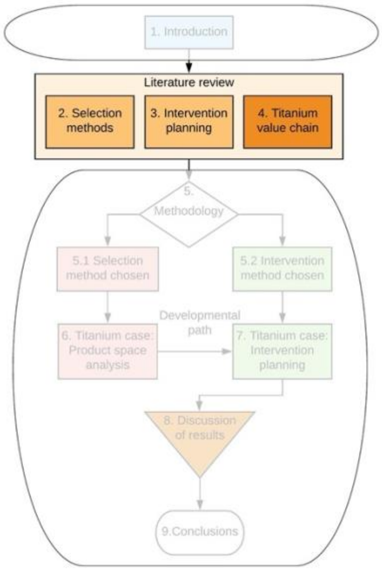

Figure 4.1: Document progress, with focus on Chapter 4 – literature review on the titanium value chain

The purpose of this chapter is to provide an overview of the titanium value chain. Titanium's occurrence and composition are explained in Section 4.1. This is followed by the various production processes in the value chain from mining through to the final product in Section 4.2. The titanium industry is split into two markets one being the metals market and the other being the titanium dioxide market which is explained in Sections 4.3 and 4.4 respectively. Section 4.5 provides an overview of the key industry players on an international level. Section 4.6 provides an overview of where South Africa currently lies in the titanium value chain in terms of mining and production as well as current barriers and opportunities. The chapter concludes with Section 4.7 which discusses the government's general beneficiation strategy as well as the government's focus with regard to the titanium industry.

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4.1. Occurrence and composition

Titanium is the ninth most abundant natural element in the earth's crust and falls fourth on the list for most commonly used elements in structural metals following aluminium, iron and magnesium (Roskill Information Services, 2013). Titanium is mostly used in the form of titanium dioxide (TiO_2) and very little is converted to its metal form – only about 10% of these minerals are converted to metal – whilst the dominant industry is the white pigment industry (McNulty, 2007). This is primarily due to the high manufacturing costs related to producing titanium metal.

Assessing titanium metal properties against other structural metals it is found to have a number of superior properties. It has a better strength to weight ratio than steel; it has high corrosion resistance and retains its structural strength when exposed to high temperatures (Van Vuuren, 2009). With such excellent properties it is surprising that the use of titanium is not a lot more than what it currently is. One of the biggest barriers for titanium substituting steel in various industries is due to the high manufacturing costs of titanium metal products. Industries relying on steel could substitute it with titanium to increase performance due to titanium's superior qualities. This places most titanium-based products in a category of their own where sales are based on unique product performance or specialised uses, unlike steel and aluminium which are commodity products (Van Vuuren, 2009).

The main titanium-bearing minerals used to produce titanium dioxide are ilmenite ($FeTiO_3$), rutile (TiO_2) and leucoxene ($CaTiSiO_5$), a second weathering product of ilmenite. Ilmenite and rutile ores are mostly used for manufacturing white pigments, and economically exploitable deposits of these ores can be found in beach sands or fossilised dune deposits along the western coast of South Africa. Ilmenite and rutile are commonly discovered in beach sands alongside other valuable minerals such as zircon, monazite and garnet, each of which has potential economic value (van Tonder, 2010).

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4.2. Titanium production process

A broad overview of the manufacturing activities and processes involved in converting raw titanium minerals to the final product is shown in Figure 4.2 below. It stretches from the mining process through to the final products from titanium, namely, titanium dioxide and metal ingots. The titanium metal ingots are used either to produce mill products or titanium powder for powder metallurgy. The recovery rate for titanium minerals from placer deposits is generally about 90% (Gillson, 1960). Ilmenite is the more predominant mineral over rutile, as it supplies 90% of world demand (Department of Mineral Resources, 2011). Although the sulphate process has certain capabilities, such as being able to use lower quality feedstock and produce pigment in anatase form ideal for paper and ink, the chlorination process being a more cleaner process is preferred over the sulphate process (Department of Trade and Industry, 2016). From the 4 million tons of titanium dioxide produced worldwide in 2013, 40% came from the sulphate process and 60% from the chlorination process (Department of Mineral Resources, 2011). The Kroll process is the generally preferred process to produce titanium sponge used to produce titanium metal. Approximately 10% of global mining production is used for the manufacture of titanium metal (USGS, 2019).

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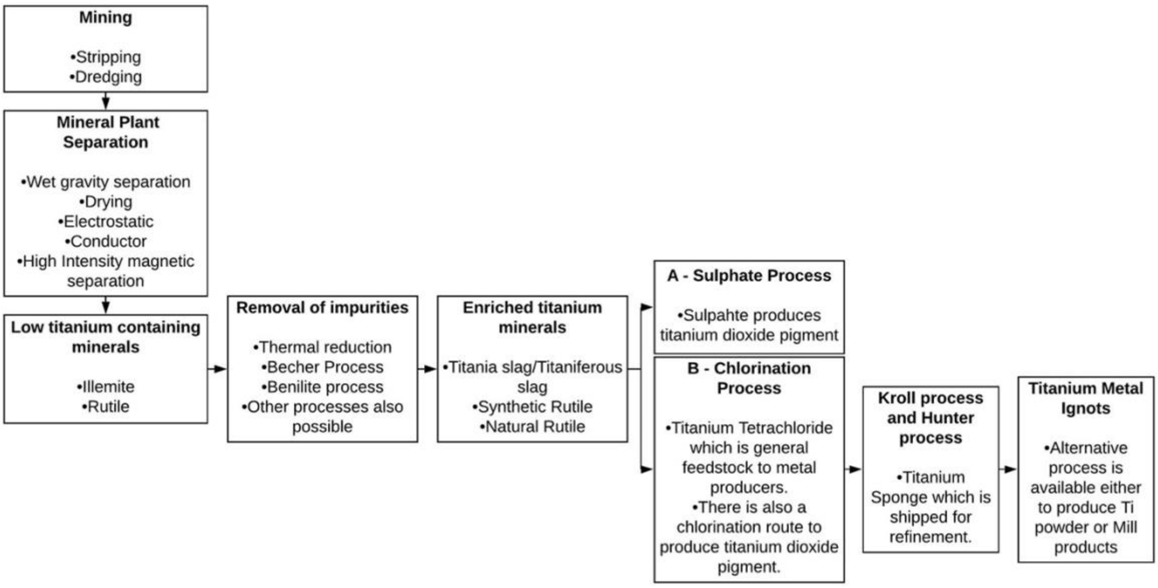

Figure 4.2: General overview of some processes involved in the production of titanium-related final products (Williams and Steenkamp, 2006; McNulty, 2007; van Tonder, 2010; Department of Mineral Resources, 2013b; Gambogi and Gerdemann, 2013; Roskill Information Services)

4.3. Titanium metal industries

The applications for titanium metal can be found in numerous markets such as aerospace, naval, sport as well as various industrial segments as shown in Figure 4.3. These are all potential markets related to the titanium value chain that can be pursued by the South African government through supporting local development of products related to these sectors. These markets consume titanium, due to its numerous advantages. Certain industries consider the application and benefits of these properties to be more important than the high cost of the metal. The following examples are mentioned in Van Vuuren's (2009) keynote address: “Titanium – an opportunity and challenge for South Africa” at the CSIR.

Aerospace applications – The high fuel demand within the aerospace sector pushes the industry into seeking more solutions for higher fuel efficiency. One way of achieving higher fuel efficiency is to decrease the weight of the aircraft by using lighter and stronger materials, and the unique strength-to-weight ratio of titanium renders it as a suitable solution (Gambogi and Gerdemann, 2013). Its other unique properties such as its high-temperature strength and compatibility with carbon-reinforced composites, make titanium a suitable metal for the

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aerospace industry. These unique characteristics are leading to the amount of titanium being used in new models of aircraft increasing. Due to the technology enabling more fuel-efficient aircraft, the demand for aircraft is increasing, which in turn is increasing the demand for titanium.

Armaments industry – As with aircraft, the lower weight of titanium allows for applications that require manoeuvrability, high strength for gun barrels and bulletproofing. Decreasing the weight of armoured vehicles can increase manoeuvrability and increase the chances of troops' survival.

Naval Applications – Titanium is resistant to corrosion in seawater. Furthermore, its light weight makes it ideal for applications in naval vessel bridge structures, as it effectively lowers the centre of gravity of these vessels.

Offshore oil industry – Although the use of titanium means high costs, the cost of an oil spillage and underwater repairs due to corrosion from seawater far outweigh the costs of using corrosion-resistant titanium. The lighter titanium metal allows for easier installations and hence decreases the cost of installation and strengthens the economic argument for choosing titanium.

Water desalination and the chemical industry – The desalination of seawater is becoming more popular as the world's water demands are increasing with the increasing population. The Cape Town drought is a good example where desalination is considered as a potential solution. Titanium's corrosion-resistance is making it the metal of choice for such plants. It is also the reason why the chemical industry is attracted to titanium, as it helps with safekeeping of equipment against premature failures and lowering the maintenance costs involved.

The following industries also have great potential for the use of titanium metal in each industry. These industries are power-generating industries through the use of steam turbines, the automotive industry, architecture, sports and leisure and medical applications. The main properties of titanium that attract these industries are: strength-to-weight ratio, resistance to corrosion, bio-compatibility and compatibility with various composites and high-temperature strength.

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A very simplified structure of the titanium metal industry is shown in Figure 4.3. There are some large integrated companies that cover large segments of the industry and there are also some that provide specialised services in niche segments. With a local industry, enterprise development across all of these segments can be expected.

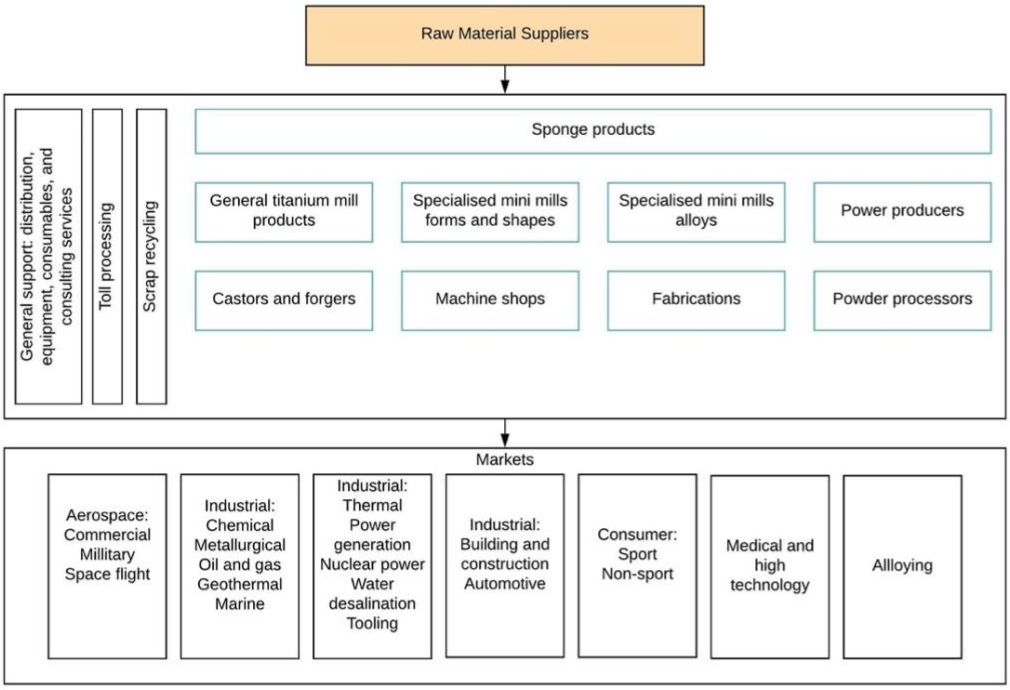

Figure 4.3: Structures of the titanium metal industry (Van Vuuren, 2009)

4.4. Titanium dioxide industry

The biggest demand for titanium is from the pigment industry that is responsible for consuming about 90% of all the titanium feed stocks. Most of the titanium dioxide is used in the pigment industry due to its numerous inherent characteristics which make it very attractive. These characteristics include (Department of Mineral Resources, 2013a):

- Its opacity and whitening properties, enhances colour and quality properties;
- Its colour retention;
- Its chemical stability;
- Its thermal stability;
- Its inertness and non-toxicity;

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- Its excellent whitening capabilities; and
- Its high refractive index, light-scattering capabilities and reflectivity.

Thus, titanium dioxide is a fundamental ingredient in a wide range of industrial and consumer products (RSC - Advancing the Chemical Sciences, 2016). Titanium dioxide pigments are mainly used for manufacturing paints, paper and plastics (Gambogi and Gerdemann, 2013). Other industries also include food, pharmaceuticals (toothpaste, sunscreen and cosmetics), catalysts, ceramics, coated fabrics and textiles, floor covering, printing ink and roofing granules. A broad overview of the main consumers of titanium dioxide is shown in Figure 4.4 below.

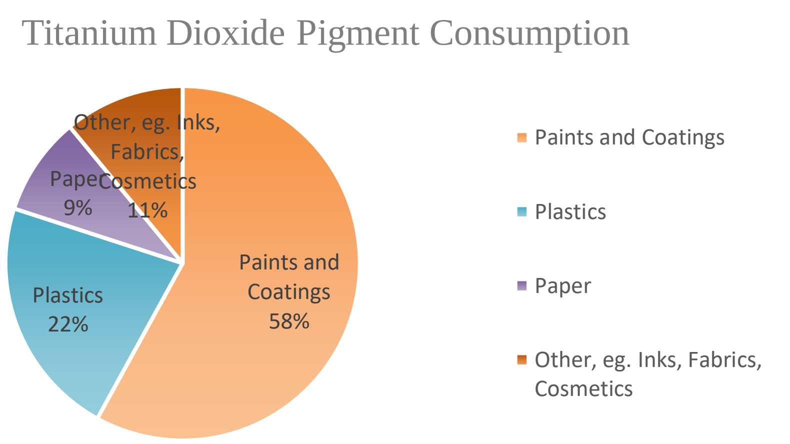

Figure 4.4: Global titanium dioxide pigment consumption (Department of Mineral Resources, 2012)

From Figure 4.5 below that is based on the United States titanium dioxide market, can be seen that paints and coatings are the largest segment within titanium dioxide, as it has numerous beneficial applications such as opacity, exterior durability and an acid-catalysed coating. It is specifically used for interior architectural paint and coatings for its good hiding capabilities. The plastic segment also consumes a big amount of titanium dioxide, especially in the manufacture of doors and windows. Europe is the second-largest market with a growing personal care industry and countries such as the UK, Germany, France and Italy will also see the demand for titanium dioxide increase. Countries such as China and India are also expected to drive the demand up, as there is a rise in popularity for personal care products among the male population.

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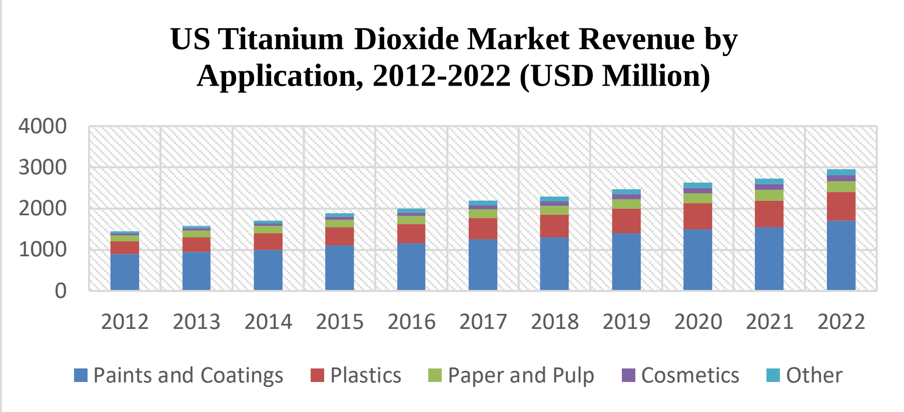

Figure 4.5: US titanium dioxide market revenue by application, 2012-2022 (USD Million) adapted from (Bulk Chemicals | Grand View Research: Titanium Dioxide Market Trends 2015 To 2022 by Grand View Research, Inc., 2012)

4.5. International players in the titanium industry

South Africa is the world's fourth largest producer of titanium-bearing minerals (specifically ilmenite and rutile) following Australia, Canada and China with 10 percent of the 6,1 megatons (Mt) of global production as can be seen in Table 4.1 (USGS, 2019). According to USGS (2019), Canada and South Africa primarily produce titaniferous slag from all the mining activities. South Africa is in the third place behind Australia and India for the largest quantity of mineral reserves, which indicates the ability of South Africa to support a titanium industry.

Table 4.1: World mine production and reserves, all amounts shown in Mt (USGS, 2019)

Country	Production	Reserves
Ilmenite		
United States	100	2,000
Australia	700	250,000
Brazil	50	43,000
Canada	850	31,000
China	850	23,000
India	300	85,000
Kenya	280	54,000
Madagascar	100	40,000
Mozambique	600	14,000
Norway	200	37,000

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Senegal	250	NA
South Africa	500	63,000
Ukraine	230	5,900
Vietnam	200	1,600
Other Countries	150	26,000
World Total (Ilmenite)	**5400**	**880,000**
Rutile		
United States	*Included above*	*Included above*
Australia	250	29,000
India	10	7,400
Kenya	90	13,000
Mozambique	8	880
Senegal	8	NA
Sierra Leone	170	490
South Africa	100	8,300
Ukraine	100	2,500
Other Countries	10	400
World total (Rutile)	**750**	**62,000**
World Total	**6,150**	**942,000**

From Table 4.1 it is evident that South Africa has one of the largest mineral ore reserves, yet, when looking at Table 4.2 below, South Africa is neither mentioned as a country with sponge production nor as one with sponge or pigment production capacity. This indicates that South Africa currently processes an insignificant amount of its own mineral mine productions. However, should South Africa decide to further process minerals and leverage current production to develop downstream capabilities, it can drastically change production patterns.

Interestingly, when comparing Table 4.1 and Table 4.2 it is observed that countries such as Kazakhstan, Japan, Germany, Russia and the UK are now represented in Table 4.2, indicating they are not active in mining production, but have the facilities for sponge and pigment production. According to Roskill Information Services (2013), the leading exporters of titanium products are Kazakhstan, Japan and China with the leading importers being the USA, UK, Russia and Germany. Table 4.2 also supports the fact that most titanium industries produce titanium pigment with the countries' combined pigment capacity being 7,660,000 Mt compared to sponge capacity of 293,000 *Mt*.

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Table 4.2: World sponge metal production and sponge and pigment capacity shown in Mt (USGS, 2019)

Country	**Sponge production**	**Capacity**	
		Sponge	**Pigment**
United States	W	13,100	137,0000
Australia	-	-	260,000
Canada	-	-	104,000
China	70,000	110,000	3,250,000
Germany	-	-	47,2000
India	500	500	108,000
Japan	52,000	68,800	314,000
Kazakhstan	9,000	26,000	1,000
Mexico	-	-	300,000
Russia	40,000	46,500	55,000
Saudi Arabia	500	15,600	210,000
Ukraine	8,000	12,000	120,000
United Kingdom			315,000
Other countries			784,000
World Total	**180,000**	**293,000**	**7,660,000**

Developments in the titanium industry have been quite significant since the year 2001, as the price of titanium sponge increased by 130% between the years 2001 and 2006 (John Barnes, Doblin and Lathabai, 2014). The titanium market is exposed to several risks and difficulties, which makes potential investors nervous and thus makes it difficult for the industry to secure potential investors. The other major barrier in the titanium market is that its current size is still relatively small, which implies that buyers and sellers are very concentrated leading to volatility caused by supply and demand variability.

4.6. South Africa’s titanium value chain

Looking back at Table 4.2 in Section 4.5 it is evident as mentioned before that South Africa has the third most titanium ore reserves in the world with the fourth highest mining production rate and yet does not stand out in sponge production or even having the capacity for sponge and pigment production. Although it might be difficult to achieve, South Africa could start mineral processing activities to diversify its economy, reduce its dependence on industrialised countries, develop transferable skills and increase economic rents (Bam and De Bruyne, 2019).

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South Africa has had a comparative advantage in mineral resources for some time and still the level of beneficiation remains very low and concentrated in high capital sectors (The Department of Trade and Industry, 2017). This is an indicator that having the natural resources does not automatically translate to downstream beneficiation, requiring dedicated interventions to address the barriers that are limiting the exploitation of beneficiation opportunities. The following barriers were identified by the Department of Trade and Industry:

- Limited access to raw materials for local beneficiation, the majority of the producers are stuck in long-term contracts with international clients, limiting the access of raw materials for local manufacturers;
- Shortage of critical infrastructure such as rail, water, ports and electricity supply affects the sustainability of beneficiation initiatives and future growth in mineral value addition;
- South Africa has limited exposure to breakthrough research and development programmes;
- For South Africa to expedite local beneficiation, specific attention has to be given to skills requirements for scientists and engineers; and
- Access to international markets for beneficiated products.

Therefore, before thinking of establishing a local industry, there are some technological barriers that also need to be overcome by South Africa. In an article written by D.S. Van Vuuren from the CSIR (van Vuuren, 2009), the following few key technological requirements were identified for South Africa to establish a local industry:

- Cost reductions along the titanium value chain, including the side stream activities, although the research will focus on downstream activities. South Africa will need to be competitive in sponge and pigment production;
- South Africa's distance from markets and mass balance of the industry makes it uneconomical to import metals for fabrication and then to export large volumes of scrap. Local manufacturing should work on reducing scrap materials; and
- Lastly, sufficient effort should be put in place for the minimisation of chemical waste, as the disposal of such products can be an expensive exercise. With growing concerns of global warming, all effort is made to reduce the carbon footprint which adds another layer of complexity, as the production of titanium is very energy intensive.

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The sections below provide more insight into South Africa's current position with regard to mining (Section 4.6.1), manufacturing (Section 4.6.2) and the position within the product space (Section 4.6.3).

4.6.1. Mining

For South Africa, ilmenite and rutile are the major economical titanium minerals and are predominantly found along beaches on the eastern, southern and northern coasts of South Africa. Richards Bay Minerals (RBM), Namakwa Sands, Fairbreeze Mineral Sands and Nyaza Light Metals are mines that are either currently in operation or anticipated to open soon. With additional supporting projects such as the CSIR Ti-powder production (refer to Figure 4.6 below), the process attempts to avoid the expensive Kroll process. South Africa is starting to make advancements towards enabling further developments in the titanium market.

RBM is situated in KwaZulu-Natal at Richards Bay and is the leading producer of titania slag, high purity pig iron and rutile in South Africa (Williams and Steenkamp, 2006). Two registered companies, namely, Tisand (Pty) Ltd and Richards Bay Minerals and Titanium (Pty) Ltd (RBIT) operate under RBM. Tisand is responsible for dune mining and mineral separation while RBIT controls the smelting and beneficiation process. This forms one of the largest single mining operations in South Africa and is co-owned by BHP Billiton and Rio Tinto plc. With annual production of 1 Mt titanium slag and 20 years' worth of reserves given current production rates, BHP is the largest titanium slag producer in the world. Namakwa Sands, which was recently acquired by Exarro, is another major player in the production of titanium slag (Gous, 2006).

RBM (Tisand) is involved in heavy mineral sand mining by means of dredging and separating the mineral fraction in a floating separator (Williams and Steenkamp, 2006). Heavy mineral sand is separated through gravity spirals whilst heavy mineral constituents are separated with magnetic and high-tension circuits. Ilmenite is beneficiated to synthetic rutile or titaniferous slag. The heavy mineral is then transported to an RBM plant 7 km inland for separation of minerals into ilmenite, rutile and zircon fractions. Ilmenite is smelted and transformed into titanium slag and pig iron is recovered as an important by-product. The slag is then milled and

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classified into two suitable raw material product sizes for the respective sulphate and chlorination processes.

The South African titanium industry is primarily established in the first section of the titanium value chain, which is represented as the raw section in Figure 4.6. RBM (Rio Tinto) established themselves to the extent that they conduct activities from mining through to producing titania slag. The titania slag is primarily exported and partly sold to the local market. Local markets consist of companies such as Nyaza Light Metal (partly owned by Evraz and Arkein International) that makes use of the sulphate process to produce titanium pigment. Other mines are Namakwa Sands, KZN Sands – Hillendale Mine and Fairbreeze Mineral Sands, all owned by Tronox, which all only mine ilmenite and rutile and export the raw materials. Similar to Tronox is MRC that owns Tormine mine and Xolobeni mine and also exports ilmenite and rutile in raw form without any further processing.

Before its closure, South Africa had the potential of producing about 20 000 tons of titanium dioxide from titanyl sulphate at Huntsman Tioxide in Umbogintwini in KwaZulu-Natal (Department of Mineral Resources, 2013a). They were the only company to produce titanium dioxide (TiO_2) in South Africa. Huntsmen Tioxide utilised a small portion of the titanium slag produced in South Africa, as it only had a 25 kt per annum capacity titanium pigment plant. Beneficiated products are then sold further downstream to international and local consumers (Department of Mineral Resources, 2008). South Africa does not yet have facilities or the technology to perform the chlorination process, which partly explains why 95% of the country's titanium minerals are sold to the export market.

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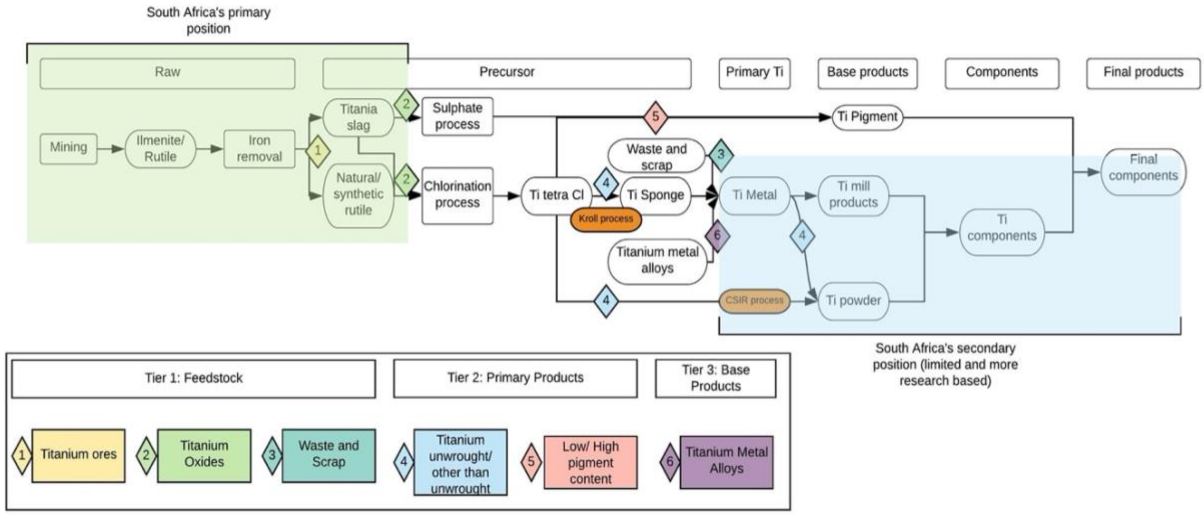

Figure 4.6: Overview of titanium value chain showing where South Africa is currently placed (Williams and Steenkamp, 2006; McNulty, 2007; van Tonder, 2010; Department of Mineral Resources, 2013b; Gambogi and Gerdemann, 2013; Roskill Information Services, 2013)

4.6.2. Manufacturing

There are several South African companies (some in collaboration with international companies) already established in the titanium industry, operating under the components and final products section of the value chain shown in Figure 4.6. The following companies are mentioned to give a brief overview of these companies and the industry in which they are operating. Southern Plants is in the dental industry producing dental implants from bars through turning processing. Comair International is in the biomedical industry producing implants from billets and bars by turning and milling. In the Aerospace industry are Aerosud, Denel Aviation and Dalif who produce aerospace components from billets, bars and powder by turning and milling. Denel Aerostructures and Aerosud, South African-based companies, produce titanium aerospace parts for major aviation companies such as Airbus and Boeing (DTI, 2017). Denel Aerostructures produced parts for a military Airbus A404 that is said to contain about 9 tons of titanium metal per aircraft (Denel Aerostructures, 2010). It is evident from the examples above that these companies are primarily based in the titanium metal section within South Africa. South Africa has only produced pigments locally, implying that the companies mentioned above had to import the bars, billets and powder for processing.

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The following two case studies show where two South African companies have started to make inroads within the titanium value chain and industry under government-supported programmes (DTI, 2017):

- *Aeroswift* – mainly deals with high-speed additive manufacturing (3D printing) for large metal parts. The Department of Science and Technology (DST) has been funding various research endeavours in the additive manufacturing regime. Aeroswift is one of the projects being funded by DST, based on its potential to unlock new industries if the project is successful. In 2016 the first titanium aerospace parts were produced on the Aeroswift machine. These parts then completed their first flight in 2017. The aim for the second phase of development will be aimed at industrialisation of the technology used by Aeroswift for commercial use; and
- *Ti-Tamed* - is a small and medium-sized enterprise (SME) manufacturing company specialising in precision engineering of materials such as titanium, stainless steel, invar (nickel-iron alloy) aluminium and high-performance polymers. Under the Department of Trade and Industry (DTI) supplier development scheme, Ti-Tamed served as a development partner for Aerosud Aviation. This partnership allowed Ti-Tamed to grow and become an aerospace supplier. The partnership assisted in thorough technology transfer and improved throughput, thus allowing more business opportunities. This shows the importance of the right policies allowing international collaboration and technology transfers. This will in return spill over to local companies, allowing easy knowledge and technology transfers moving forward.

There are, however, various institutions collaborating in an attempt to develop new technologies, which will allow the local manufacture of primary titanium and base products. Institutions such as the CSIR are currently busy researching and further developring the CSIR process, and various tertiary institutions are collaborating with industry partners.

4.6.3. South Africa's current position

It is important for South Africa, when choosing new products, to consider which products can contribute the most in terms of strategic value. The question is which products in the titanium value chain will place South Africa in a favourable position in the open forest for best exposure to easily move over to new products. When products with high strategic value are selected, it

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is generally those that fall in densely packed areas and thus create significant value for future structural transformation. Thus, it means choosing sectors in the titanium industry that potentially unlock opportunities not only in the titanium value chain, but in alternative value chains as well. Thus, South Africa's current problem is its existing footprint in the product space, implying that if it selects products with similar capabilities it will move to products with little strategic value. Reaching products with greater strategic value will require a higher initial investment cost, as more capabilities need to be developed, if South Africa keeps on targeting the same areas. Hausmann & Klinger (2008b) stated that agriculture continues to have the potential to act as a springboard for modern structural transformation in South Africa, although the chemical products and machinery sectors represent the highest strategic value products. This highlights the role of titanium, as there is use for titanium-related products in both sectors. Figure 4.7 below shows South Africa's location in the product space in 1975, which is represented by the black squares and is on the outskirts of the product space. The long-term goal for South Africa will be to target products that will allow for economic growth as well as open up numerous additional opportunities.

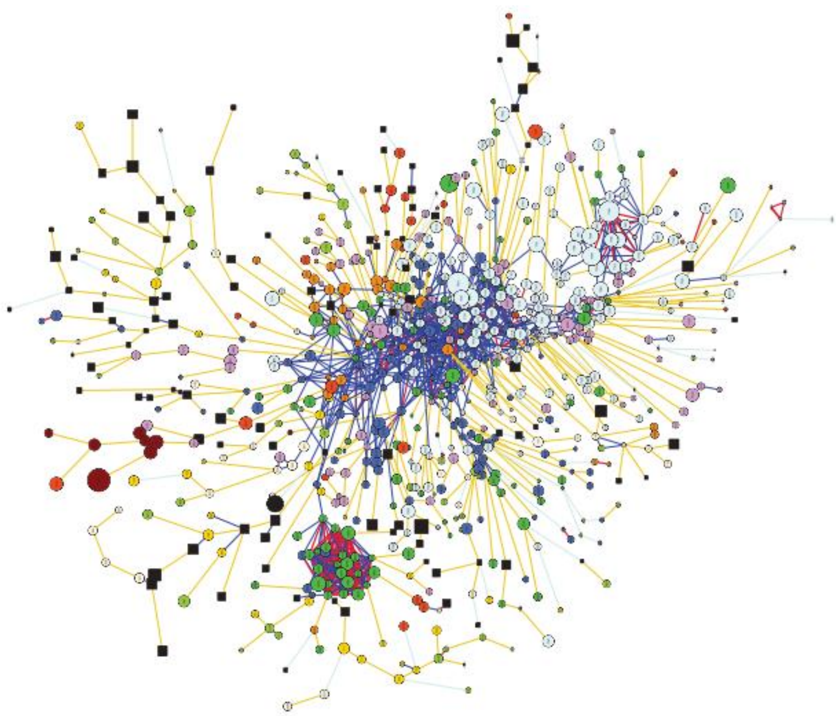

Figure 4.7: South Africa's location on the product space in 1975 with black squares indicating an exported product with comparative advantage - Sourced from Hidalgo et al. (2007)

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In Figure 4.8 below the products for which South Africa does not yet have a comparative advantage are shown, with the density showing their distance from the current set of capabilities and the strategic value these products can offer. The upper left quadrant would ideally be the products to target, as products in this quadrant offer high strategic value and are close to South Africa's current set of capabilities. When evaluating Figure 4.8 it is evident that chemical- and plastic-related products are within close proximity, but offer very little strategic value. Moving higher up towards products that offer higher strategic value, one finds metal fabrications and the top strategic value sector which is machinery. Although sectors such as agriculture (currently placed at 'ideal' in Figure 4.8 below) are mainly in the efficient frontier, other sectors such as machinery, chemicals, metals and plastics contain both attractive and unattractive sectors. Thus, a thorough selection process needs to be applied when selecting products for beneficiation (Hausmann and Klinger, 2008b).

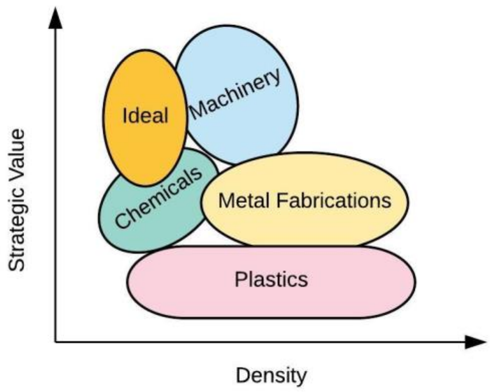

Figure 4.8: Strategic value versus density of product groups which South Africa can target (Hausmann and Klinger, 2008b)

4.7. Government mineral beneficiation strategy

The potential offered by titanium has been identified and recorded in numerous governmental studies and has therefore also been included in various national science and technology strategies. The key strategies identified included:

- *Foresight studies* – In the late 1990s the former Department of Arts, Culture, Science and Technologies commenced various foresight studies as part of its directive to reform

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the South African science and technology system. The mining and metallurgy foresight study recommended that the government and industry should collaborate in research and development in the production of titanium and titanium oxide from the available local raw materials;

- *Chemical sector development strategy of the DTI* – the Titanium Beneficiation Initiative (TBI) forms part of a few key programmes involved in the implementation plan of the Chemical Sector Development Strategy of the DTI. The strategic challenge of the TBI is to achieve the necessary level and quality of beneficiation for titanium slag so as to prevent long-term revenue decreases within the broad-based mining sector (Barcza, 2000); and
- *The national advanced manufacturing technology strategy* – the Minister of Science and Technology is advised by the National Advisory Council of Innovation (NACI) on various technological innovations. In 2002 NACI recommended the development of a National Advanced Manufacturing Technology Strategy (AMTS) for South Africa. Light metals development such as titanium was identified as one of the lead projects. The project led to the formation of the Light Metals Development Network (LMDM) that is administered by the CSIR as part of the Advanced Metals Initiative (AMI) (NACI, 2003).

The above-mentioned strategies indicate that there is interest from the South African government in the titanium industry and willingness to assist with development within the industry. Numerous universities are also currently working in alignment with TiCoC, in order to enhance titanium beneficiation activities within South Africa. Powder consolidation is being researched at the University of Cape Town and Stellenbosch University. The latter university is also researching high performance machining whilst the Central University of Technology is working on high-speed additive manufacturing (CSIR, 2016). In Sections 4.7.1 and 4.7.2, South Africa's current policy frameworks and potential opportunities for targeting titanium is discussed.

4.7.1. Cross-cutting constraints and current policy framework

In Section 4.6 barriers and limitations for South Africa towards beneficiation and intervention of raw minerals were discussed. The government has implemented interventions to moderate

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these limitations and provide the best chances of successfully implementing interventions. In Table 4.3 below each limitation is discussed as to how the government can leverage instruments at its disposal to counter the limitations and actions that can be taken by businesses.

Table 4.3: Cross-cutting activities and interventions established by the government (DTI, 2017; InvestSA, Deloitte Africa and DTI, 2020)

Cross-cutting constraint	**Potential instruments at government disposal**	**Action by business**
Limited access to raw material for local beneficiation.	Leverage the state's custodianship of the country's minerals to facilitate downstream beneficiation.	Take advantage of the Mineral Value proposition to expand local demand for mineral ores; and comply with legislation.
	The Mineral and Petroleum Resources Development Act (MPRDA) is currently amended to strengthen beneficiation provisions.	
	Leverage the beneficiation offset element of the Mining Charter.	
	Strengthen provisions within existing pieces of legislation such as the diamond export levy to promote reliable and competitive access to raw materials, utilising the Preferential Procurement Policy Framework Act.	
	Address import-parity pricing especially of steel and heavy chemicals, including, if necessary, through export taxes, conditionalities placed on infrastructure, and regulation.	
Shortages of critical infrastructure.	Identify specific infrastructure needs over the next 10 to 20 years, with the Critical Infrastrucuture Porgram (CIP).	Align production plans with national programmes.
	Ensure that existing infrastructure planning mechanisms and programmes such as the critical infrastructure programme properly consider infrastructure requirements for mineral beneficiation.	Embrace energy efficiency.

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	Leverage on the New Growth Path (NGP), which seeks to unlock infrastructure bottlenecks through massive expansion of transport, energy, water and communications capacity.	Explore co-generation prospects.
	Utilise the state's infrastructure (public good) as an effective instrument to promote local beneficiation.	
Limited exposure to research and development.	Align beneficiation-related research and development requirements (both current and recurrent) to the national ten-year plan for science and technology. The Technology and Innovation Cluster Program (TICPS), further developing critical skills and knowledge. Further promote the Technology Innovation Agency (TIA), providing engineering servies to small and medium enterprises.	Support and develop competitive technologies.
Inadequate skills.	Align the beneficiation skills pipeline to the national skills development strategy and the sector skills plans for required skills.	Investment in human capital development.
	Promote skills development and partner with the relevant Sector Education and Training Authorities (SETA) and institutions of higher learning for training and labour development.	Cooperate with government to leverage and enhance the national skills development strategy and the sector skills plans for required skills.
Access to international markets.	Review existing and ensure that future trade agreements adequately support the beneficiation intent (FDI and market access). Also currently targeting to be top 50 in ease of doing business ratings by 2022.	Leverage on trade agreements.
	Take advantage of the comprehensive strategic partnership with China to support investment in beneficiation in South Africa as well as access to markets in China.	

The government set up a strategic framework including a selection of enablers that allows for effective implementation of mineral beneficiation in South Africa. The enablers consisted of a

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combination of framework and structures shown in Figure 4.9. Knowing what structures and frameworks are available in South Africa will be of great use when setting up intervention planning initiatives.

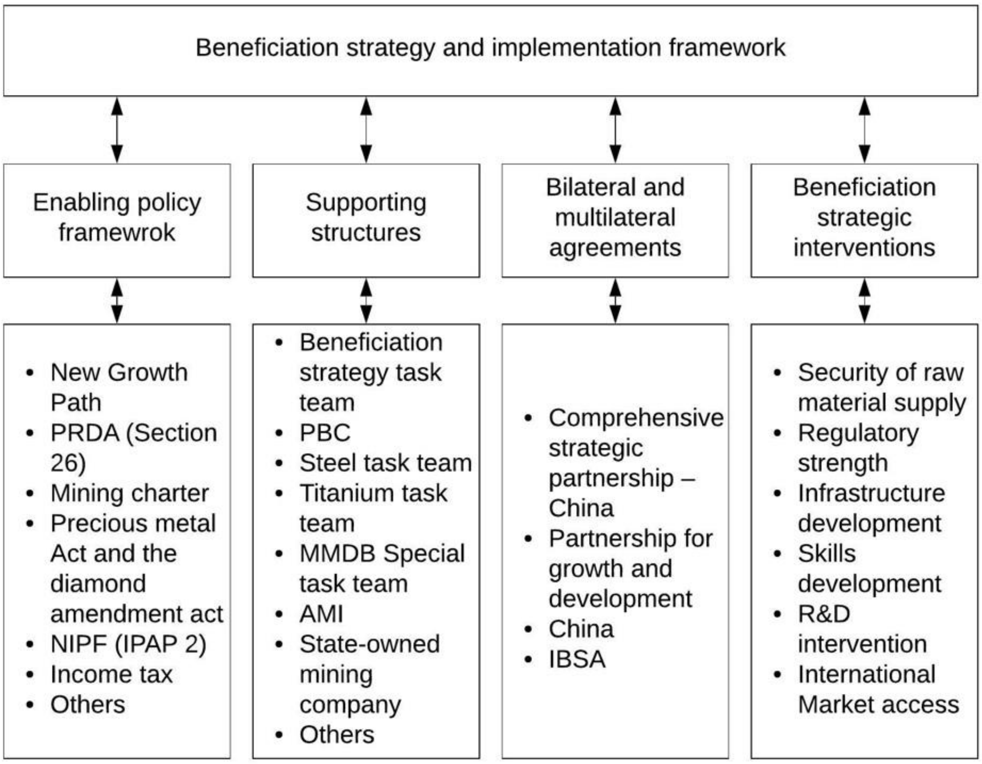

Figure 4.9: Beneficiation strategy and implementation framework developed by (Department of Mineral Resources, 2011)

4.7.2. Potential of selecting titanium according to the government

In a report written by the Department of Mineral Resources (2011), discussing 10 selected minerals and 5 value chains, the titanium pigment and metal industry was specifically highlighted. The development of the titanium value chain is identified as a potential key growth sector for South Africa (Department of Mineral Resources, 2011). The growth in demand is driven by the more common urban uses and personal consumption of titanium dioxide. Cheaper manufacturing processes will allow titanium to displace other metals, as it has superior properties. According to the Department of Mineral Resources (2011) (DMR) an inter-departmental task team was formed to promote titanium beneficiation and establish a titanium

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industry in South Africa. Interventions for the pigment and metal production development that have been identified include:

- Fundamental research funding into the production of titanium from the Bushveld Titano-Magnetite. Such facilities will also spill over into the steel value chain, as iron can also be produced;
- Developing a more cost-effective and proprietary titanium metal production process is regarded as a key enabler for establishing a local industry;
- Developing and commercialising technologies to cost-effectively compete against the international market;
- Developing an infant titanium industry including the required infrastructure to support South Africa's entry into the titanium market, commercialising technologies and developing human capital to sustain a future large-scale industry;
- Investing in casting capabilities for titanium alloys needs to be developed and demonstrated, developing key technology platforms with local competence and capacity in areas such as powder metallurgy of titanium and machining;
- Commitment from mining companies ensuring access to the minerals and continued interaction with global pigment producers to ensure the government (DTI, DMR, DST and other stakeholders) knows what is required to establish a plant in South Africa;
- Investigating the viability of establishing a chlorine plant in conjunction with a pigment plant. A second potential stage is to establish titanium metal production on the back of titanium tetrachloride for pigment production, followed by titanium metal fabrication for aerospace, automotive, leisure and medical sectors; and
- Continued research and development of mineral beneficiation, preparation of intermediate metal salts, their purification and metal manufacturing itself.

These interventions have already paid dividends with a number of beneficiation projects becoming operational in recent years (DTI, 2017). The first project is Tronox that has opened its new Fairbreeze mineral sands mine in KwaZulu-Natal, estimated to be worth R3.3 billion. Fairbreeze produces high-quality ilmenite to feed the smelters at Tronox. The mine has created 250 direct jobs and 1 000 jobs indirectly. The first R2.6 billion phase has already started and will be followed by the second phase over a six-year span, accumulating to R3.3 billion. The second project is Nyanza Light Metals (in collaboration with New Zealand's Avertana Ltd) that completed its pilot plant testing of the Evraz Highveld Steel & Vanadium plant's waste

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steel slag to produce titanium pigment in the Richards Bay industrial development zone (Department of Trade and Industry, 2016). This makes it the only plant to produce titanium pigment, after the closure of Huntsman Tioxide in Umbogintwini in 2015, creating 1 300 jobs. Construction started in 2018 with production expected to start in 2020. Various co-products such as aluminium sulphate, magnesium sulphate and gypsum can be produced with the Avertana process, opening up numerous other potential opportunities.

Research projects include new radical innovations such as the patented CSIR Ti-powder process that has the potential to generate new industries. The development of the CSIR's Ti-powder production process reached another milestone after having completed and reconditioned the pilot plant (Department of Trade and Industry, 2016). In November 2016 the first commercially pure titanium was poured at this plant. Additional processes are being developed for downstream manufacturing of titanium alloys. The DST has allocated an additional R105 million over three years from 2016, from the high-end-infrastructure fund, to accelerate the technology maturation process. In addition to accelerating the technological development, relationships are formed with major aircraft original equipment manufacturers (OEMs) and industrialisation partners for the eventual industrialisation of these technologies (Department of Trade and Industry, 2016). This will see direct titanium metal powder being produced at significantly lower costs.

4.8. Chapter summary

In this chapter key benefits were mentioned that can potentially be realised by South Africa if interventions are established successfully. An overview of the titanium value chain, in terms of pigment and metal, was given, as well as where South Africa currently lies within the titanium value chain. The chapter also assessed the international players involved so as to assess where South Africa has a competitive advantage and where it is lacking. The chapter concluded with the discussion of the government's current beneficiation strategies and where initiatives have already paid dividends.

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Chapter 5

Methodology

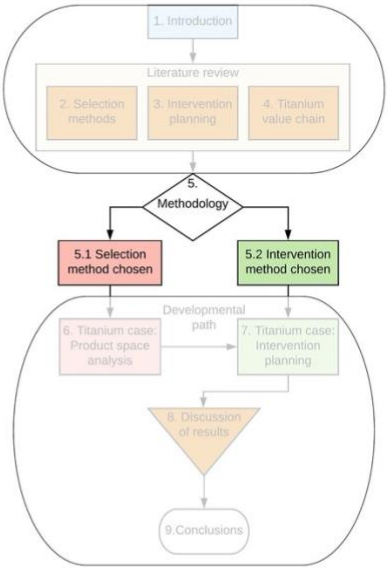

Figure 5.1: Document progress, with focus on Chapter 5 – Methodology

This chapter discusses the methodology used to analyse the titanium value chain as well as the framework that was used to establish the appropriate intervention plans for targeting the identified sectors. In Section 5.1 the details of the appropriate industry selection method are discussed as well as how the method was applied. Section 5.2 focuses on intervention planning for the selected industries. Figure 5.2 shows the process that was followed. The green highlighted parts indicate the first part focusing on analysing the titanium value chain and identifying the most strategically fit sectors for South Africa to target. Once the segments had been identified, the next phase that is highlighted in red, was to identify how South Africa could penetrate into the identified market segments through establishing the most important market and locational factors for supporting the industry. Once these factors have been identified, interventions planning can follow accordingly.

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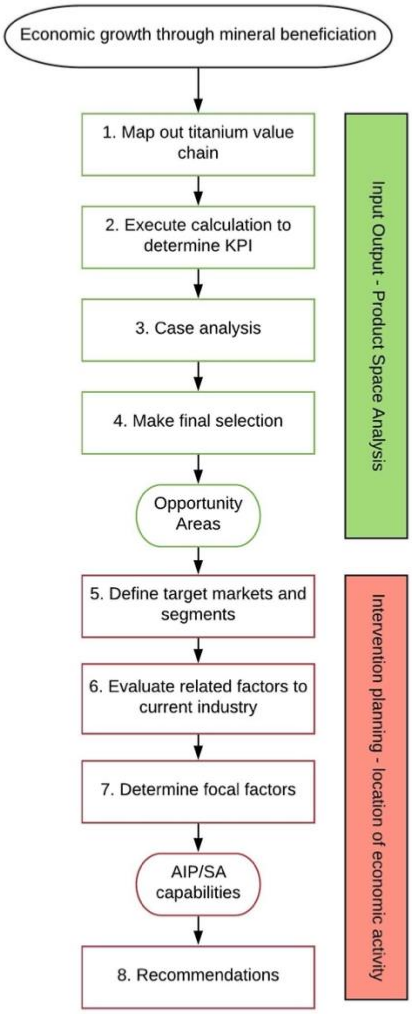

Figure 5.2: Strategy development and implementation

5.1. Application of selection method – IO-PS

In Sections 5.1.1 to 5.1.4 the methodology for executing steps 1 to 4, highlighted in green, in Figure 5.2 as well as identifying the opportunity areas are explained.

5.1.1. Mapping of value chain

The data used for the study was obtained from the MIT Observatory for Economic Complexity (OEC) website (https://atlas.media.mit.edu/en/resources/data/). In the case of the Harmonised System (HS) data analysis, the HS6 Rev. 1992 data at a 6-digit depth was used whilst the

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Standard International Trade Classification (SITC) data analysis made use of SITC4 Rev2. 1992 at a 4-digit depth. OEC sourced the databases from the BACI International Trade Database for HS and UN COMTRADE for SITC respectively.

Firstly, the titanium value chain was mapped out using the HS 6-digit Rev 1992 trade codes that were taken from the MIT observatory for economic complexity website and searching for the respective titanium related products within the database. The mapping was done from top to bottom (in Table D.1 Appendix D and Table E.1; Appendix E for HS and SITC respectively) with the rawest products first and moving towards more refined products to the bottom, essentially moving up in tiers. The products were grouped together into product groups in such a way that they can be targeted by policies.

5.1.2. Key metrics used

The code that was used for analysis was the MATLAB code developed by Bam and De Bruyne (2019), shown in Appendix F. The purpose for using both trade data systems was to evaluate the consistency of the method. Different results could be expected, as the 6-digit trade codes allow for a more in-depth categorising of products than the 4-digit. However, a general conversion would increase confidence in the results. For this step respective CSV files were created with the tiers, categories and trade codes as the content for the file which was used in the MATLAB simulation.

For the country-specific analysis, three specific metrics were considered, as these metrics give the most strategic insights. These metrics, calculated by the MATLAB code, can be used to discuss the different optimal beneficiation routes. These metrics are:

i. Complexity – this metric is an important indicator towards understanding how each product category can contribute towards the potential economic growth of South Africa, as increasing complexity is a predictor of increasing growth;
ii. Distance – this metric gives an indication of how difficult (i.e. costly) it will likely be to attain an RCA for products within the category; and
iii. Opportunity gain – this gives an indication of how much products within a product category can contribute towards developing capabilities that could support the ability

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of South Africa to reach out and start producing products with higher complexity in the future.

Other metrics such as proximity and RCA were also calculated during the MATLAB simulation that was used to guide the analysis. Optimisation calculations were run through MATLAB, calculating the optimal combinations given certain distance constraints.

5.1.3. Analysis of metrics

The analysis started with a generic industry analysis, as the key indicators such as complexity and proximity were used to analyse the value chain at tier and product level. The results of this analysis were expected to follow the traditional beneficiation narrative, although the results were broad and potential obstacles could be overlooked.

Thus, the analysis moved towards a more country-specific analysis by establishing in which sectors of the value chain South Africa had already been performing well, and by assessing the opportunity gain and distance towards other products in the product space. This analysis was applied at tier and category levels, which provided valuable insight.

The analysis continued towards a more dynamic analysis where trade-offs between distance, opportunity and complexity were calculated. The different scenarios were based on maximising the complexity of the country or maximising opportunity gain for the country with different distances used. The best metrics were selected respective to the scenario under consideration, i.e. is the country targeting more complex products or products that will allow more opportunities in the future.

The analysis also included a brief comparison between the HS and SITC trade codes, testing the robustness of the IO-PS calculations.

5.1.4. Final selection

Initial ratios such as opportunity gain per distance were used on individual categories to identify the top categories in the titanium value. Three strategy routes, namely, conservative,

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middle and aggressive could be selected from the dynamic analysis for both the complexity and opportunity maximising cases. The top categories based on opportunity gain per distance ratios and complexity were assessed against these strategies to confirm whether a category was a valid option. If the category did not fall within one of these strategies, the next best category had to be selected until the best option was found.

It has to be noted that during the literature review, it was established that numerous unknowns are unaccounted for during an optimisation run. Thus, the categories were selected based purely on the most optimal key metrics. South Africa's current industry footprint (current research, collaborations and manufacturing) is also mapped, allowing the researcher to assess if any of the top identified categories are aligned with South Africa's current footprint and which is deemed most fit to focus on during the next phase of analysis.

5.2. Application of location-centric framework

Once the key sectors had been identified, steps 5 to 8 in Sections 5.2.1 to 5.2.4 highlighted in red in Figure 5.2, were executed. The goal was to identify the most important key factors necessary for the identified industries to be successful at a certain location, in such a way that the necessary changes to the country's current policies and beneficiation strategy could be recommended or implemented. It also allowed assessing whether pursuing the sectors was realistically achievable for South Africa.

5.2.1. Defining target markets and segments

The analysis started off by first analysing the specific products within the category that were identified as most strategic for South Africa to pursue. The analysis involved assessing each product within the category to determine the best product to pursue. The analysis went further by evaluating the top import and exporters globally, allowing an insight into where the markets were dispersed geographically. The top collaborators with South Africa for each product were also assessed.

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5.2.2. Evaluate the industry chosen

The next step moved away from the location-centric framework and was aimed at broadly identifying the market-related dynamic requirements related to the specific products that were selected to be analysed. The market's competitive landscape, with regard to how industry leaders were maintaining market dominance, was assessed. This was followed by analysing the supply chain for the market, allowing complete understanding of the various components involved in the specific market. Once the market surrounding the product had been well defined, the location-centric framework could be applied.

5.2.3. Determine focal factors

As previously discussed in Section 3.4.3, the location-centric framework is designed to be generic and to be applied to any industry; thus the dimensions were used as a starting point and the multiple factors included in the framework were narrowed down to those that had clear bearing on the sector of the titanium industry identified in the previous phase.

Referring once again to Table 3.3 in Section 3.4.3, the first dimension is aimed at assessing who will win the market share through understanding the customer requirements and determinants. The main focus for this phase was to assess what factors were essential for that specific market or industry and how well-equipped South Africa was towards supporting the industry. Dimension 2 assesses what is essential for the industry in terms of industry and firm moderators and assessing the extent to which South Africa is capable of supporting the specific industries. Trade barriers are also assessing this dimension. Dimension 3 finally evaluates the specific market and location-related factors; the factors are assessed according to what the market values as most important. For the rating of the factors relating to each dimension, a questionnaire was sent out to current industry leaders to get a clear rating of the respective factors related to each phase of the location-centric framework. The various questions were related to finding ratings for the factors in the different phases of the framework. Each phase related to one of the 3 dimensions discussed in Section 3.4.3. Although the questionnaire was also aimed at providing insights towards Sections 5.2.1 and 5.2.2.

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The key aspects targeted by the questionnaire, located in Appendix J, are indicated in Figure 5.3 below which is a layout of the location-centric framework discussed in Section 3.4.2. The orange icon with a 'Q' indicates the specific area targeted by the questionnaire. The different phases of the location-centric framework, as discussed in Section 3.4.2, are indicated in oval blue shapes in Figure 5.3. Thus, it can be seen that the questionnaire targeted more than just an understanding of the three dimensions which are shown in the green ovals. The aim is to achieve an importance rating on the respective factors and an indication from the industry how they currently portray South Africa's contribution towards supporting these factors.

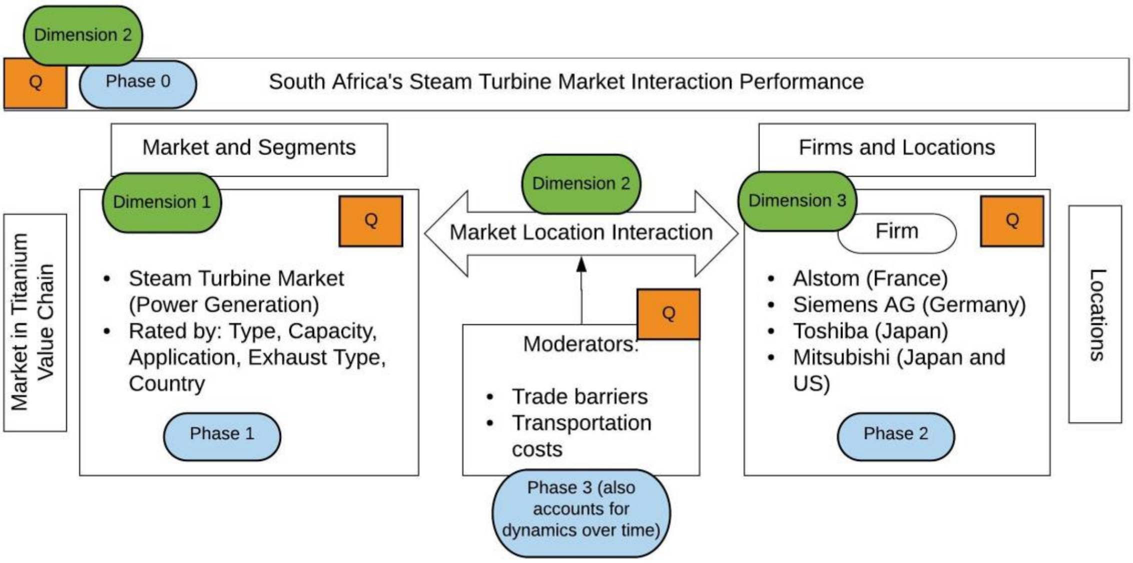

Figure 5.3: Layout of the application for the location-centric analysis framework adapted from (Bam, De Bruyne and Schutte, 2020)

The phases discussed below refer to the generic location-centric framework indicated in Section 3.4.2 and attempt to provide insight as to how the questionnaire was established and how the dimensions that are primarily used for guiding the intervention planning fit into the framework.

Dimension 1 – primarily relates to phase 1 (questions 1, 3, 4 and 7a) and focuses on establishing the customer and market types related to the specific activity. The most important question is question 3 which focuses on the requirements for winning market share through rating the importance of the cost of products, quality of products, responsiveness to market changes and lead time. It should be noted that question 7a and 7b classifies as the same question in the

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questionnaire, although key deductions relevant to market requirements and location are possible; therefore a split was established through 7a and 7b. Key deductions regarding specific product information, the geographical locations of industry leaders and market share are assessed in Sections 5.2.1 and 5.2.2 to provide further insights into the analyses. The questionnaire sought to extend this analysis by obtaining a more in-depth understanding of the different markets from the perspective of the main producers.

Dimension 2 – partly relates to phase 0 and factors discussed in Appendix C (questions 2 and 6) which dealt with setting the unit of analysis that defines the activity under consideration, and what key factors are required to support such an industry. The questionnaire asked experts the importance of moderating factors specifically related to the industry such as complexity of production processes, dynamism of the product market environment, the importance of knowledge spillovers and economies of scale so as to get a better understanding of the activity and industry performance potential. It is important to understand these factors as the more specific intervention plans can be established to support the industries.

Dimension 3 – relates to phase 2 (question 7b specifically) where the specific locational factors are assessed based on what the market values most important from dimension 1. The questionnaire asked experts specific location-related factors linked to the market factors established in the previous phase, hence the question is labelled as 7b. The location performance dimensions related to the various important market factors such as cost, quality, lead time and so forth are related to manufacturing.

The rest of the questions provide valuable insight towards analysing the results. The moderators asked in question 5 provide valuable insight into which factors are likely to become more influential, as there is a potential of reaching advanced markets once the local industry is growing. Moderators such as trade barriers, transportation cost, interaction costs and political factors between the countries are rated. The information obtained from Sections 5.2.1 and 5.2.2 also provides valuable insight into refining the intervention plan, as more insight into market size and segments and the geographical location of current leaders and top partners is obtained.

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5.2.4. Rating of the key factors

The feedback on the questionnaire can be placed in the respective quadrants as shown in Figure 5.4 below. Based on into which quadrant the factors fall, the respective priority can be given during the intervention plan feedback. The quadrants represent the importance to industry and country assistance for each factor so that the factors can be targeted accordingly. Depending on the quadrant and the extent to which the country is contributing towards obtaining the key factors, respective strategies for the intervention plan can be presented.

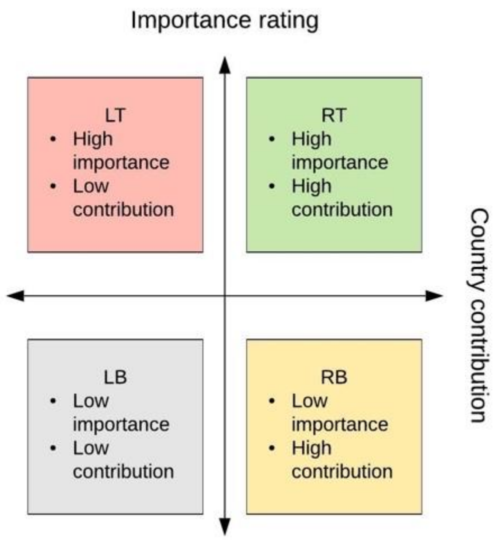

Figure 5.4: Classifications of most important factors and moderators

Factors classified as low contribution imply that South Africa has either limited power to assist those factors or they have not received any attention. In a case where low contribution is required the factor might be classified as low importance. Thus, the importance rating is based on whether South Africa is already assisting in the industry or not assisting and has to intervene to support industry.

The quandrants are as follow:

- *LT:* The factors within this quadrant are very important, but are currently either outside South Africa's control or South Africa still has to target these factors accordingly;

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- *RT:* This quadrant is related to the factors that are of high importance for the industry that South Africa can control and is currently contributing towards achievement. Thus, factors within this segment are the ones South Africa would use, for example, to attract FDI;
- *LB:* Contains factors of low importance to the industry, whilst South Africa is not contributing anything towards attainment of these factors. There is no need for South Africa to spend critical resources on these factors; and
- *RB*: Contains factors that are not important to the industry, but certain inherited capabilities are allowing South Africa to contribute towards them. No immediate action is required for factors in this quadrant.

The most important quadrants that the intervention planning should initially focus on are the two top quadrants. The quadrants indicate South Africa’s current shortfalls in the industry (based on the important factors) and assessing the extent to which the shortfall can be addressed through correct policies.

5.3. Chapter summary

The chapter discussed the analysis techniques and calculations involved in each method of analysis selected. It also discussed how these analysis techniques were applied for the respective methods. For the first phase it was decided to use the IO-PS analysis to identify the most strategic sectors followed by the location-centric framework. In the second phase it was important to grasp the most industry-related factors for a location to support the identified market.

Although the metrics are deemed optimal for the sector, the accuracy of the intervention planning can be hampered due to numerous unknowns involved with targeting an industry for which South Africa does not have an RCA as of yet.

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Chapter 6

Titanium case: Input-output product space analysis on value chain

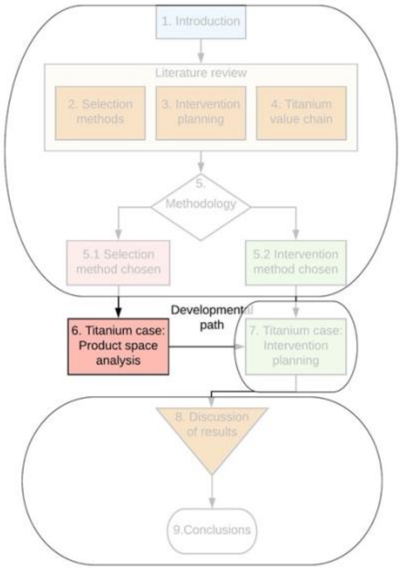

Figure 6.1: Document progress, with focus on Chapter 6 – IO-PS analysis

In this chapter the IO-PS analysis is applied on the titanium value for South Africa. The analysis starts with Section 6.1 that consists of a generic industry analysis. Although both the HS and SITC trade codes were used during the analysis to evaluate the robustness of the results, the primary focus remained on the results provided by the calculations on the HS trade codes. Section 6.2 provides an analysis more specifically based on South Africa's productive structure introducing the key perspectives guiding the evaluation. Section 6.3 provides a brief overview of the results obtained from an SITC run, which is followed by Section 6.4 discussing the comparison of the results derived based on the HS and SITC trade codes, respectively. Section 6.5 provides a final evaluation of the results and also provides key recommendations based on South Africa's current industry footprint.

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6.1. Generic industry analysis

The literature review served as the one input to the input-output map of the industry. The US Bureau of Economic Analysis (BEA) input-output tables were also used as a guide when identifying the various trade codes linked to the titanium value chain. Titanium ores, titanium waste and scrap and titanium oxides were used as the baseline and from these industries the various industries linked to them were mapped out and used in the initial calculations. In the case where HS trade codes were used, a total of 173 products were identified and were divided into 45 categories and for SITC trade codes a total of 45 products were identified and 26 product categories. The categories and trade codes for both HS and SITC are shown in Appendix D and Appendix E respectively. The categories are selected in such a way that the products within each category can be targeted collectively by the government if a category is considered strategically fit. The tiers were created based on the input and output relationships, hence products in tier n consume products in tier n-1.

Figure 6.2 provides an overview of the generic titanium value chain divided into respective product categories, based on the HS trade codes. Also, in Figure 6.2 the complexities of each product category can be seen, as calculated from the MATLAB code, with the number of products within each category shown in square brackets. The tier complexities are also shown, and all product complexities are averaged regardless of whether the RCA > 1 or RCA < 1. The proximities are also shown for products with proximities higher than 0,4. This is to highlight the product categories with the largest proximities to each other. Throughout the rest of the chapter the figures and tables all follow a colour coding with red being the least desirable to green being the most desirable. It has to be noted that for complexity and opportunity gain, higher values are more desirable, hence they are marked green. For distance on the other hand lower values are more desirable, hence the lower values are marked green.

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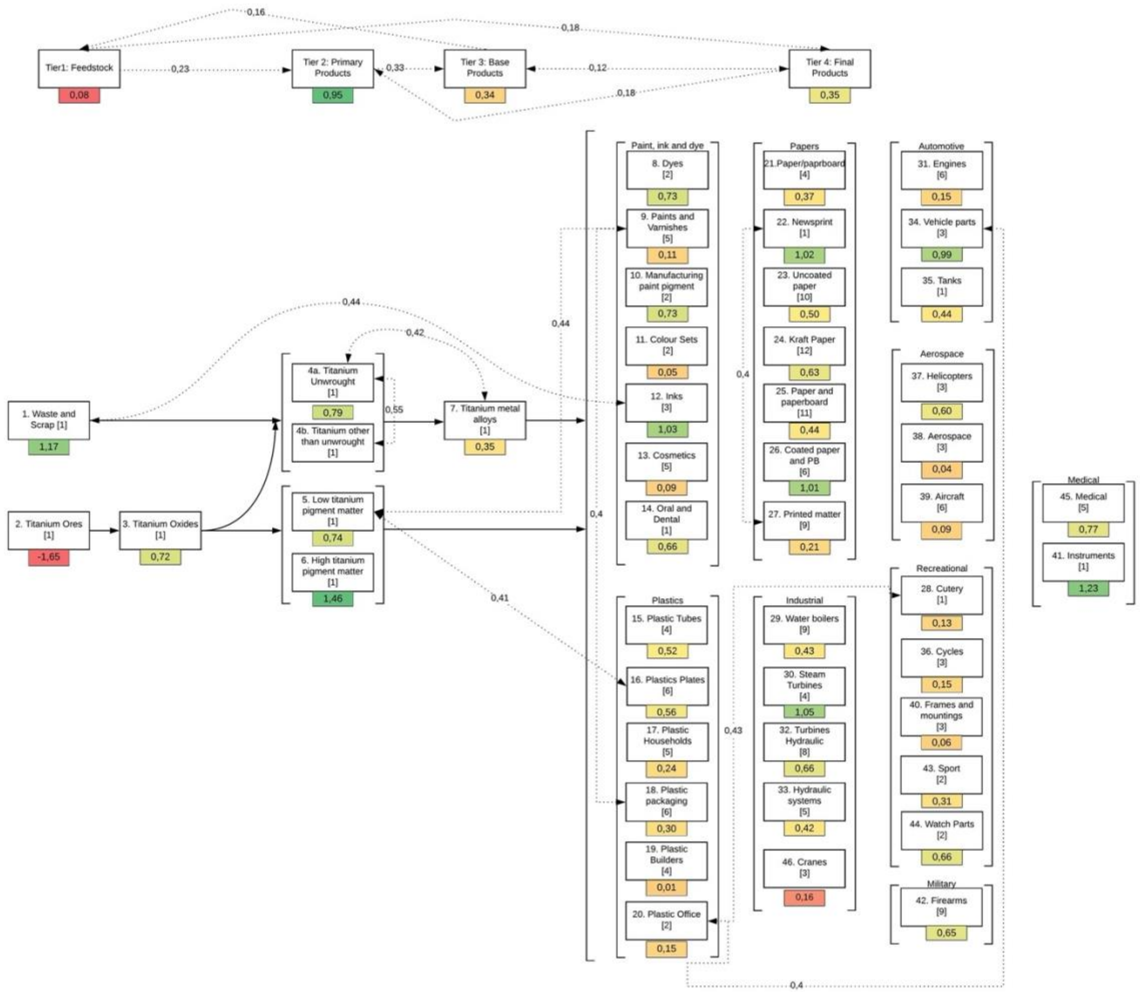

Figure 6.2: HS 6-digit aggregated (tier level) and product category level for Titanium's value chain with global complexity scores and high (>0,4)

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6.1.1. Tier level

Considering Figure 6.2, it is visible that tier 2 has the highest complexity and consists of primary products. It specifically includes product categories 4a (titanium unwrought), 4b (titanium other than unwrought), 5 (low titanium matter pigment) and 6 (high titanium matter pigment). For the remainder of the study only the product number is indicated, with the full description available in Appendix D. Tier 1 is the least complex and fits into the classic beneficiation narratives, as products further down the value chain are expected to be more complex. Tier 1 consists of two extreme complexities with the waste and scrap category being highly complex. Waste and scrap come in various forms and have already been through manufacturing phases. Titanium ores is the least complex category. Tier 4 has the second highest complexity although it is expected to have the highest complexity if the classic beneficiation narrative is followed. As mentioned before, 95% of the titanium minerals are used in the pigment industry and the products produced in the pigment industry are not the most complex products, which could lead to the lower complexity. Most of the highest complex product categories in tier 4 are those produced from titanium metal.

When examining the tier-to-tier proximities the highest proximity is found between tier 2 and 3 with tier 1 and 2 having the second highest proximity. This is a positive indicator, as for many minerals it is difficult to move from tier 1 to tier 2, while for titanium, according to the proximities, it is not the biggest bridge to gap and might be easier accessible than initially expected to be.

Evaluating tier levels at a glance can give one a brief indication of where the potential opportunities or stumbling blocks can be found in the value chain. However, there are some misconceptions that can creep through. Some categories such as 41 and 26 have higher complexities than most product categories; for example than in tier 2, yet tier 2 has a higher average complexity due to one category raising the average.

6.1.2. Product category level

The same argument used in Section 6.1.1 applies for targeting categories with the highest complexities with the mindset that it will be more economically beneficial to target such

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categories. Sometimes categories with lower complexities will have better connections (proximities) to more product categories, which will be more beneficial for countries in the long run. Briefly analysing Figure 6.2, it is more advisable to target categories 1 and 12, as both of them have high complexity values and are in close proximity to each other. Thus, gaining an RCA for the one has a high potential for allowing the country to gain an RCA for the other. Other categories with high complexities and good proximities to other product categories include 34, 22 and 6. Targeting these categories also leads to an appropriate split between the pigment and metal industries and are good examples of high complexities and high proximities, exposing new possibilities to those countries with newly required capabilities and skills. The ideal product categories for a country to target will depend on which strategy it will follow. With a short-term focus, it might be better to target high complexity categories. With a longer-term focus, it might be better to target products with high opportunity gain.

The product category perspective presented is still generic and not country specific. This means the current capabilities of the country and its ability to facilitate the attainment of certain categories are not considered. Furthermore, the country-specific new capability development potential of the various products is not considered either. This is addressed in the following country-specific analysis.

6.2. Country-specific analysis

The country-specific analysis process evaluates the results from the following three different perspectives:

i. *Focal country footprint* – The first perspective considers the footprint of the country being focused on (South Africa). This allows an assessment of which categories within South Africa are already performing well i.e. categories with products having an RCA > 1 on average. The country's current footprint indicates the difficulty of attaining an RCA for the rest of the products in the category. The reason why it is sometimes better, is because the product category already has an RCA > 1 and it might be easier and cheaper to obtain an RCA for the rest of the products in the category that do not have an RCA as of yet. In return it can also "unlock" other categories for the country;

ii. *Opportunity gain* – Instead of looking at the proximity values as was done with Figure 6.2, this approach considers opportunity gain instead. Using this approach allows the

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search for product categories to focus on categories within close proximity to other product categories with high complexity rating. Thus, if an RCA is successfully achieved, the country the country moves closer to other high complexity products; and

iii. *Distance* – Considers how difficult it is expected to be to attain an RCA for the products for which an RCA > 1 has not yet been attained. Considering only the proximity to products in the value chain can potentially lead to ignoring the possibility that the country might have an RCA for products in a different value chain, but with similar capability requirements than those in question. However, distance is calculated considering all the products in the product space for which a country has an RCA > 1.

In the following two sections, the above three metrics are considered at both the tier and product category level, respectively, using the HS trade code mapping of the value chain.

6.2.1. HS tier level analysis

Now that the new analysis perspectives are established, the analysis can start with these three new perspectives included. In Table 6.1 assessing tier level 1, it strengthens the beneficiation argument with only tier 1 having an RCA > 1, which is 16,052, with the rest of the tiers all having an RCA < 1. Table 6.1 also shows the average complexity, distance to and the opportunity of the products within each tier for which the RCA < 1.

In Table 6.1 it is evident that tier 2 has the highest average complexity and opportunity gain, which is an indicator that South Africa should be focusing there as those two indicators give the perspective that the products within tier 2 will allow economic growth and unlock various new opportunities. Tier 4, on the other hand, has the second highest RCA average, but the complexity, distance and opportunity gain are not as impressive compared to the other tiers. Looking from a complexity perspective it will be wise to focus on tiers 1 and 2, and if the distance is bridged it seems to get easier to bridge the gap to the lower tiers, but what will it cost to bridge the gap? From this quick overview it is evident that at tier level there are contradicting values or rather trade-offs that are difficult to assess. Basing policies on tier averages is therefore not ideal, as the results are not consistent and there might be products within a category that are either pushing the averages up or down. Therefore, a more comprehensive analysis at category level was undertaken and is presented in Section 6.2.2.

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Table 6.1: HS case-specific (South Africa) metrics aggregated at tier level

Tier#	Average RCA	Average complexity for product with RCA < 1	Average distance for products with RCA < 1	Average opportunity gain for products with RCA < 1
1	16,052	0,719	0,869	0,295
2	0,135	0,948	0,847	0,302
3	0,235	0,349	0,847	0,177
4	0,530	0,401	0,852	0,144

6.2.2. Product category level

The product category level static analysis is presented in Table 6.2. The first column indicates the average RCA for each product category. High values mean more products in the category have RCAs >1 or that those products with an RCA >1 have very high RCAs which are pushing the average up. The next two columns are the average complexity of all the products in the value chain and the total opportunity if the focused product category can be successfully targeted, i.e. all the products in the category eventually get an RCA > 1. At the top of Table 6.2 one can see South Africa's initial average complexity that is 0,001. Such a low initial complexity means one can target almost any product group and it will still lead to an increase in the average complexity. The last column shows the sum of distances to the products in each product category given the current product structure. A higher distance value implies there are more products and more distant products in the category with an RCA < 1. In general, Tier 4 products have higher distances, but that is not the case for all product categories in tier 4, as there are numerous categories with low distances. This starts to show that it is not impossible to target further downstream categories while skipping their predecessors (without first working through the first couple of tiers). This can lead to higher economic benefits for South Africa by targeting more specific downstream activities with less initial investments required and with higher yields when compared to normal beneficiation strategies. Thus, it can be seen that optimal routes may sometimes consist of "leap-frogging" steps.

Analysing Table 6.2 by looking at columns 3 and 5 specifically with a distance point of view, it seems that categories 10, 22, 28, 39 and 41 are close by and seem easy to obtain, but when looking from a complexity point of view they might not be as strategically beneficial as they have low complexities. When looking for categories with high complexities it seems that

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categories 23, 24, 25, 26, 32, 42, and 45 prove to have the highest complexities, but considering their distances it can be expected to be more difficult to pursue those categories. As mentioned earlier, it might also be necessary to have a more sustainable long-term approach, to look at which product categories become "unlocked" as a result of pursuing certain categories. Column 4 gives an indication of categories to target by looking at opportunity gain, and from Table 6.2 it is evident that categories 24 and 25, 32 and 39 have the highest opportunity gain.

Table 6.2: HS metrics for South Africa at the product category level

Product Category #	Average RCA	Average Complexity of the products within the VC if all products within the category have a RCA > 1	Opportunity gain if all products in category have RCA > 1	Sum of distances to products in category
Baseline		0,001		
Tier 1				
1	1,022	0,001	N/A	N/A
2	46,638	0,001	N/A	N/A
3	0,496	0,028	0,202	0,869
Tier 2				
4	0,047	0,060	0,379	1,699
5	0,106	0,029	0,037	0,840
6	0,339	0,057	0,214	0,849
7	0,235	0,014	0,124	0,847
Tier 3				
8	0,514	0,055	0,185	1,751
Tier 4				
9	0,458	0,020	0,108	4,133
10	0,767	0,037	0,319	0,881
11	0,139	0,005	0,116	1,710
12	0,497	0,111	0,570	2,563
13	0,563	0,023	0,525	3,358
14	1,573	0,001	0,000	0,000
15	1,181	0,011	0,000	0,000
16	0,113	0,108	0,339	5,068
17	0,407	0,032	0,069	3,348
18	0,508	0,057	0,286	4,958
19	0,381	0,000	0,011	3,346
20	0,087	0,012	0,052	1,706
21	0,228	0,051	0,030	3,278
22	0,514	0,045	0,149	1,692
23	0,686	0,145	0,481	5,092
24	1,282	0,199	0,997	9,343
25	0,555	0,146	0,962	7,640

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26	0,107	0,197	0,884	5,161
27	0,247	0,056	0,492	7,672
28	0,214	0,006	0,023	0,853
29	0,482	0,115	0,281	6,858
30	0,093	0,145	0,837	3,478
31	1,462	0,032	0,493	2,557
32	0,682	0,144	1,050	5,975
33	0,268	0,071	0,684	4,339
34	0,852	0,073	0,257	1,718
35	2,780	0,001	0,000	0,000
36	0,027	0,017	0,000	0,000
37	0,750	0,045	0,197	0,816
38	0,792	0,021	0,296	1,701
39	0,448	0,017	0,939	5,074
40	0,063	0,007	0,228	2,659
41	0,253	0,048	0,221	0,861
42	0,301	0,161	0,707	6,856
43	0,049	0,024	0,134	1,785
44	0,009	0,050	0,095	1,772
45	0,108	0,119	0,948	4,319
46	0,462	0,016	0,508	2,528

6.2.3. Dynamic analysis through complexity, opportunity gain and distance constraint tradeoffs

A dynamic analysis was used to determine the theoretically optimal combination of the product categories from both a complexity and opportunity gain perspective under different distance constraint scenarios. The complexity maximising case can be viewed as focusing on shorter-term economic growth, while the opportunity gain maximising case can be viewed as focusing on longer-term economic growth. The different distance scenarios evaluated for each optimisation strategy provide decision-makers with a range of options that are theoretically optimal for different levels of ambition (distance). Within this distance constraint the country seeks to maximise the selected goal metric by one or more product categories up to three consecutive categories being targeted (three being the limit due to simulation runtime and three consecutive product categories being viewed as a sufficient planning horizon). The simulation is dynamic insofar as it accounts for the changes in distance and opportunity gain values that materialise after the attainment of a product category. The simulation then optimises for the combination of product categories that will lead to the maximum total change in complexity or

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opportunity value attainable for a given distance, while considering the optimal sequence of categories that will be able to minimise the total distance traversed to attain the focal categories. The results of this analysis are indicated in Table 6.3 and Table 6.4 below. The following were determined for each table:

i. The optimal (sequence of) targeted product categories for fixed-distance constraints for each objective;
ii. The resultant average complexity of products within the value chain;
iii. The opportunity gain within the product space;
iv. The average distance to the remaining products in the value chain with RCA < 1 and
v. The average distance to the remaining products in the product space with RCA < 1.

The distance constraints chosen for the simulation are derived from the frequency distribution of the total distances of the products in each product category in the titanium chain for the focal country. For titanium, 12 out of the 45 categories have a total distance < 1 (with 4 of the categories being 0, as there is no product in the category with an RCA < 1). The furthest product category had a distance of 9,343. The minimum distance constraint was chosen to be 1, as it provided a low enough baseline to consider less than 20% of the product categories and would not allow the consideration of a combination of more than one product category. The maximum distance constraint was chosen to be 28 (9,343 x 3) ensuring that every combination of 3 product categories would be considered for inclusion in the final scenarios. Steps of 1 unit of distance were chosen as this provided a reasonable compromise between granularity and a reduction in simulation time. With the distance gradually increasing from 1 to 28 one can see how the combinations keep changing until the combination with the maximum value is reached.

The simulation results for the complexity maximising case are presented in Table 6.3. From Table 6.3 it is evident that if larger distances can be reached, more goods or goods with higher complexities can be reached. If the government can increase the average complexity of the products, they can increase the average complexity of the value chain. This in return increases the opportunity gain by systematically “unlocking” products that reduce the average distance to other products.

From Table 6.3 conservative targets (from a distance perspective) might be considered to be product categories 6, 41, 10 and 34. The sum of the distance of the products within these

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categories is reasonably low and could therefore be expected to be reachable. At a more ambitious level, more complex product categories could be targeted, such as 12, 26 and 30. The maximum distance that would need to be traversed to these products is 17,96, which also leads to the maximum complexity combination of product categories 24, 26, 30 and 42.

Table 6.3: HS Model results for complexity maximising case

Complexity Maximising								
Distance constraint	Distance used	Product Category 1	Product Category 2	Product Category 3	Average Complexity of the products within the VC with a RCA > 1	Total opportunity gain (considering entire product space)	Average distance to products in the value chain with RCA < 1	Average distance to products in the product space with RCA < 1
Initial Metrics					0,00073	N/A	0,85196	0,85564
1	0,84939	6	0	0	0,05679	0,21409	0,85316	0,85564
2	1,71030	6	41	0	0,10037	0,43492	0,85290	0,85542
2	1,71030	6	41	0	0,10037	0,43492	0,85259	0,85522
3	2,59097	10	41	6	0,13054	0,75247	0,85259	0,85522
4	3,42732	6	34	41	0,16082	0,68839	0,85221	0,85500
4	3,42732	6	34	41	0,16082	0,68839	0,85200	0,85472
5	4,27165	6	12	41	0,19295	0,99981	0,85200	0,85472
6	5,18680	6	30	41	0,22227	1,26598	0,85169	0,85447
6	5,18680	6	30	41	0,22227	1,26598	0,85113	0,85435
7	6,04218	6	30	34	0,23783	1,29837	0,85113	0,85435
7	6,86979	6	26	41	0,26658	1,31017	0,85084	0,85406
8	7,72540	6	26	34	0,27992	1,34339	0,85064	0,85388
8	7,72540	6	26	34	0,27992	1,34339	0,85033	0,85359
9	8,56473	6	12	26	0,30406	1,64910	0,85033	0,85359
10	9,47930	6	26	30	0,32622	1,91162	0,85004	0,85334
10	9,47930	6	26	30	0,32622	1,91162	0,84948	0,85322
11	10,35258	26	30	34	0,33079	1,95432	0,84948	0,85322
12	11,18973	12	26	30	0,35168	2,25656	0,84911	0,85294
12	11,18973	12	26	30	0,35168	2,25656	0,84883	0,85270
12	11,18973	12	26	30	0,35168	2,25656	0,84883	0,85270
12	11,18973	12	26	30	0,35168	2,25656	0,84883	0,85270
14	13,71708	23	26	30	0,36038	2,14490	0,84883	0,85270
14	13,71708	23	26	30	0,36038	2,14490	0,84831	0,85211
14	13,71708	23	26	30	0,36038	2,14490	0,84831	0,85211
16	15,47339	26	30	42	0,36269	2,37625	0,84831	0,85211
16	15,47339	26	30	42	0,36269	2,37625	0,84786	0,85201
16	15,47339	26	30	42	0,36269	2,37625	0,84786	0,85201

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16	15,47339	26	30	42	0,36269	2,37625	0,84786	0,85201
18	17,96645	24	26	30	0,37870	2,64660	0,84786	0,85201

The simulation results for the opportunity gain maximising case are presented in Table 6.4. In this table, categories 6, 10 and 41 seem like good targets when lower distances are assumed, while categories 30, 12 and 45 are more appealing under larger distance constraints. At the furthest distance extreme, product categories 26, 32, 39 and 24 also become promising.

Table 6.4: HS model results for opportunity gain maximising case

Opportunity gain maximising								
Distance constraint	Distance used	Product Category 1	Product Category 2	Product Category 3	Average Complexity of the products within the VC with a RCA > 1	Total opportunity gain (considering entire product space)	Average distance to products in the value chain with RCA < 1	Average distance to products in the product space with RCA < 1
Initial Metrics					0,00073	N/A	0,85196	0,85564
1	0,88100	10	0	0	0,03705	0,31892	0,85278	0,85542
2	1,74191	10	41	0	0,08137	0,53984	0,85247	0,85522
2	1,74191	10	41	0	0,08137	0,53984	0,85247	0,85522
3	2,59106	6	10	41	0,13054	0,75247	0,85221	0,85500
4	3,44020	4	10	41	0,13066	0,91617	0,85213	0,85489
5	4,19204	6	37	46	0,00631	0,91933	0,85239	0,85468
5	4,35744	10	30	0	0,17146	1,15310	0,85132	0,85456
6	5,21841	10	30	41	0,20572	1,37115	0,85102	0,85436
6	5,99095	4	30	37	0,14356	1,40839	0,85141	0,85431
7	6,05398	4	10	30	0,21050	1,52588	0,85098	0,85422
7	6,91601	10	12	30	0,24916	1,71312	0,85041	0,85381
8	7,75477	10	12	45	0,22354	1,82260	0,85041	0,85365
8	7,75477	10	12	45	0,22354	1,82260	0,85041	0,85365
9	8,67115	10	30	45	0,24863	2,08942	0,84982	0,85353
10	9,48807	4	30	45	0,25970	2,14562	0,84986	0,85342
10	9,48807	4	30	45	0,25970	2,14562	0,84986	0,85342
11	10,34771	12	30	45	0,29285	2,32718	0,84932	0,85301
11	10,34771	12	30	45	0,29285	2,32718	0,84932	0,85301
12	11,94116	12	39	45	0,18379	2,43529	0,84987	0,85288
13	12,12415	30	33	45	0,25319	2,44238	0,84852	0,85267
13	12,85754	30	39	45	0,20674	2,69917	0,84926	0,85276
14	13,75678	30	32	45	0,30078	2,79646	0,84834	0,85222
14	13,75678	30	32	45	0,30078	2,79646	0,84834	0,85222
14	13,75678	30	32	45	0,30078	2,79646	0,84834	0,85222
16	15,35022	32	39	45	0,20150	2,90753	0,84892	0,85209

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16	15,35022	32	39	45	0,20150	2,90753	0,84892	0,85209
16	15,35022	32	39	45	0,20150	2,90753	0,84892	0,85209
16	15,35022	32	39	45	0,20150	2,90753	0,84892	0,85209
18	17,91265	25	32	45	0,28454	2,90997	0,84752	0,85104
18	17,91265	25	32	45	0,28454	2,90997	0,84752	0,85104
18	17,91265	25	32	45	0,28454	2,90997	0,84752	0,85104
20	19,61812	24	32	45	0,31847	2,94523	0,84790	0,85132
21	20,36442	24	32	39	0,24982	2,94686	0,84854	0,85135

When comparing the results of Table 6.3 and Table 6.4 it is noted that, based on maximising complexity, product categories 10, 32 and 39 were left out whilst they were included in the results based on opportunity under the most extreme cases. This shows that, when focusing on the short term only and making decisions based on maximising the complexity case, certain groups can be left out; groups that can lead to a higher total opportunity gain. Targeting these products can be expected to increase South Africa's potential to target more products in the entire product space. The key insight that was derived from the analysis was that, with regard to the titanium value chain, it is evident that the higher tiers are not necessarily the more complex tiers and that a "leap-frog" strategy proves to be more efficient than traditional strategies.

6.3. SITC comparison

A brief comparison was made with the SITC categories. The figures and tables for the SITC case can be found in Appendix E and Appendix G respectively. Looking at tier level, Figure G.1 in Appendix G, it seems that South Africa is very competitive in tiers 1 and 3 with no products in the tier with an RCA < 1. Thus, from the analysis the results seem to be similar to the HS trade codes with average distance and complexity being better in the first tiers than the later tiers. The complexity is marginally higher in tier 4 compared agaisnt tier 2. Again, this table shows results conflicting with what might be expected from past beneficiation perceptions.

Table G.1 in Appendix G indicates that South Africa has a very large RCA in categories 2 and 6 and not as high, but still larger than 1 in categories 13, 18 and 24. From a distance perspective there are some categories that are nearby to target such as 10 and 12, but not from a complexity point of view. Products 14 and 13 make sense from the complexity point of view, but not

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distance. Although, according to column 4, category 14 seems to be the best opportunity gain to pursue, but more conservative (lower distance) options will be categories 8, 9 and 19.

Table G.2 shows the most conservative combinations for complexity maximising case 9, 18 and 23. The most aggressive (best complexity but high distance) strategy is 6, 14 and 17. Table G.3 contains the most conservative (low distance) categories for opportunity gain 10, 23 and 5 with more aggressive (higher distance) approach reaches categories 14, 17 and 25. Again, opportunity gain includes categories such as 19, 25 and 5, as they might unlock categories in different value chains and increase the overall complexity.

6.4. HS vs SITC results

The MATLAB code was run for both trade code classifications, and the results are shown below. This was done to check for consistency in the results. It must be recalled that differences can be expected in the results, as the trade codes used had differences in the number of categories and classification due to using 6-digit trade codes compared to 4-digit trade codes.

From Table 6.5 below, displaying the best category for the specific metrics from each trade code, it can be seen that titanium ores have the highest average RCA in both trade codes with Kraft paper and journals (very similar capabilities required) showing the best results for average complexity. The number in the brackets after the category name indicates the number of products classified within the category, which is applicable for Table 6.6 and Table 6.7 as well. Comparing the opportunity gain and sum of distances, the difference noticed between SITC and HS is the shift from the metal industry in HS to the pigment industry in SITC. HS shows the best results for the metal industry whereas SITC shows better results for the pigment industry. The differences can be due to the classification of product categories and number of products per product category. There are also products lost when moving from 6 digits to 4 digits. Although it is interesting to compare the results, the inconsistency shows the volatility between trade codes and number of digits used. Using 6 digits is more accurate, as product categories can be specified more accurately. Thus, from Table 6.5 it is evident that the different trade codes are targeting different categories based on a category level analysis.

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Table 6.5: HS vs SITC metrics for South Africa at category level

	HS Trade Codes	SITC Trade Codes
Average RCA	2 – Titanium ores (2)	2 – Titanium ores (1)
Average complexity of the products within value chain if all products within category have an RCA > 1.	24 – Kraft paper (12)	14 – Journals (4)
Opportunity gain if all products in category have RCA > 1.	32 – Turbines hydraulic (8)	14 – Journals (4)
Sum of distances to products in category.	37 – Helicopters (2)	10 – Building Plastics (2)

Table 6.6 below shows the different strategies for each of the trade codes. These strategies are based on complexity purposes and the more aggressive approaches will require a larger initial investment. For both trade codes it seems that there is an even split between the metal and pigment industries, making it an ideal solution for South Africa. The conservative strategy is to target high pigment, plastics (consuming titanium dioxide used as both bright white pigment and protection for plastics making it more reliable and sustainable), instruments (related to chemical laboratories) and combustion parts (various internal combustion engine parts are made from titanium) that are an even split between the pigment and metal industries. A more aggressive strategy targets product groups with more products per category and again this is split between Kraft paper, paperboard, plastics and journals representing the pigment industry (majority of these use titanium dioxide either for colouring matter or as protective layers) and steam turbines, firearm parts and steam units representing the metal industry. Looking at the products per category one has to be careful that the results are not biased towards larger category groups. The split remains even between the pigment and metal markets, which leaves South Africa with the option of pursuing quantity or quality.

Table 6.6: HS vs SITC model results for complexity maximising case

Strategy	Trade Codes	Description
Conservative (low distance)	HS	6 – High pigment (1) 41 – Instruments (1) 10 – Pigments (Paint Manufacturing) (2)
	SITC	9 – Other Plastics (2) 18 – Combustion Parts (2) 19 – Gas Turbines (2) 23 – Spectacles (1)

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Aggressive (high distance)	HS	24 – Kraft paper (12) 26 – Coated paper and paperboard (6) 30 – Steam Turbines (4) 42 – Firearm parts (9)
	SITC	8 – Plastics (2) 14 – Journals (4) 17 – Steam Units (2)

From Table 6.7 the comparisons are based on the opportunity gain and it is evident that the aggressive strategy shows both trade codes targeting turbines, aircraft, steam units and paper/journals; targeting large metal-orientated categories is where the conservative approach includes a lot more of the pigment industry. The conservative approach shows the paint, pigments, plastics and low- high-content pigment industry as ideal product categories to target. If the government decides to pursue these product categories a lot of product categories that are either in the same value chain or even other value chains can be "unlocked", thus increasing South Africa's complexity in the long run. Again, it can be observed below that more aggressive strategies are targeting product categories with more products per category.

Table 6.7: HS vs SITC model results for opportunity gain maximising case

Strategy	Trade Codes	Description
Conservative (low distance)	HS	10 – Pigments – paints and manufacturing (2) 6 – High Pigment (1) 41 – Instruments (1)
	SITC	10 – Building Plastics (2) 5 – Low/High Content Pigment (1) 23 – Spectacles (1)
Aggressive (high distance)	HS	26 – Coated paper and paperboard (6) 39 – Aircraft and spacecraft (6) 32 – Turbines Hydraulic (8) 45 – Medical (5)
	SITC	14 – Journals (4) 17 – Steam Units (2) 19 – Gas Turbines (2)

From both Table 6.6 and Table 6.7 it can be observed that the more aggressive categories chosen generally tend to have more products per category. When analysing the opportunity gain case specific to HS trade codes, the product categories, 10, 30 and 32 are found in the middle of Table 6.4 at a distance of 12, but they display the highest complexity gain. Two of

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these categories are also found in the complexity maximising case, explaining why the complexity gain is so high. With the distance being in the middle, the opportunity gain obtained with a high level of complexity, reaches product categories that show great potential for further investigation. The product categories contain both pigment and metal products, with the majority being metals orientated, which can lead to potentially more complex products being manufactured. Although the results are not identical, there are still some consistencies between the categories being targeted with respective strategies. Ideally the same level of digits must be used to draw a concrete conclusion on the consistency of the results. The results in the next section are based on HS trade codes.

6.5. Taking account of South Africa's current incentives, research and collaborations

Referring back to Table 6.2 and calculating the opportunity gain per distance ratio, it becomes evident that categories 10, 30, 36 and 41 have the best ratios with respect to distance, opportunity gain and complexity, indicating that these categories can be expected to return the most benefit on investment. Categories such as 30 also correlate highly with results found from the SITC analysis. Upon further analysis, the complexity contribution for product categories 10, 36 and 4 reveals a low complexity contribution leaving product category 30 as the best category to pursue. This pushes South Africa towards pursuing industries in the titanium metal industry, but because the metal industry only consists of about 5% of the entire industry, it is advisable to pursue a product category in the pigment industry. Even though the complexity contribution of product category 10 is not the best, the market size of the industry (in terms of monetary value) could justify pursuing the industry. This highlights the potential pitfall of using the metrics in isolation.

Pursuing both product categories in the titanium dioxide and metal sectors enables the selection to achieve a balance between achieving high opportunity gains as well as an upgrade in South Africa's economic complexity structure, hence progressing towards potential stable economic growth. The dynamic evaluation of both the optimisation of opportunity and complexity cases presents the potential selection between different category combinations. These are based on the country's investment capabilities and appetite for either pursuing a conservative or aggressive strategy (in terms of distance) with regard to maximisation of either complexity or

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opportunity gain. The analysis led to the selection of category 30 as the primary target that, at category level, has the best opportunity gain per distance metric combination and is prominent in the maximisation of both opportunity and complexity cases. Based on metrics it is the best category to target and would allow for numerous other combinations to be pursued as well.

Unfortunately, choosing the developmental path on metrics alone allows for many factors to be unaccounted for. These factors can include limitations on manufacturer accessibility for the chosen industry in South Africa. Limited opportunity will be provided to engage with local industry experts, making it difficult to accurately prioritise the key locational factors that can support the profitability of an activity within the location in focus.

This raises the question of whether it is optimal to pursue an industry based on metrics alone or whether other dynamics can be considered as well. Perhaps choosing a developmental path containing other categories, in combination with the most optimal category, that is better aligned with South Africa's current industry footprint might reduce risk and facilitate the assessment process. This would allow for a developmental path that is both attractive from a metrics perspective and current industry interest. Hence, the following sections also consider South Africa's current activities in the titanium value chain (Section 6.5.1) and the overlap of these activities with the metrics-based results presented in this chapter (Section 6.5.2).

6.5.1. Current activities in the value chain

In Figure 6.3 it can be observed where South Africa's current involvement is with regard to research (turquoise), manufacturing (green) and mining (orange and blue). It is evident that South Africa has a footprint in the components and final products segment of the value chain, thus targeting categories further down the value chain (i.e. the final products) is a valid option. The manufacturing of pigment and research towards Ti powder is an indication that both metal- and pigment-related products might be attractive options to further evaluate.

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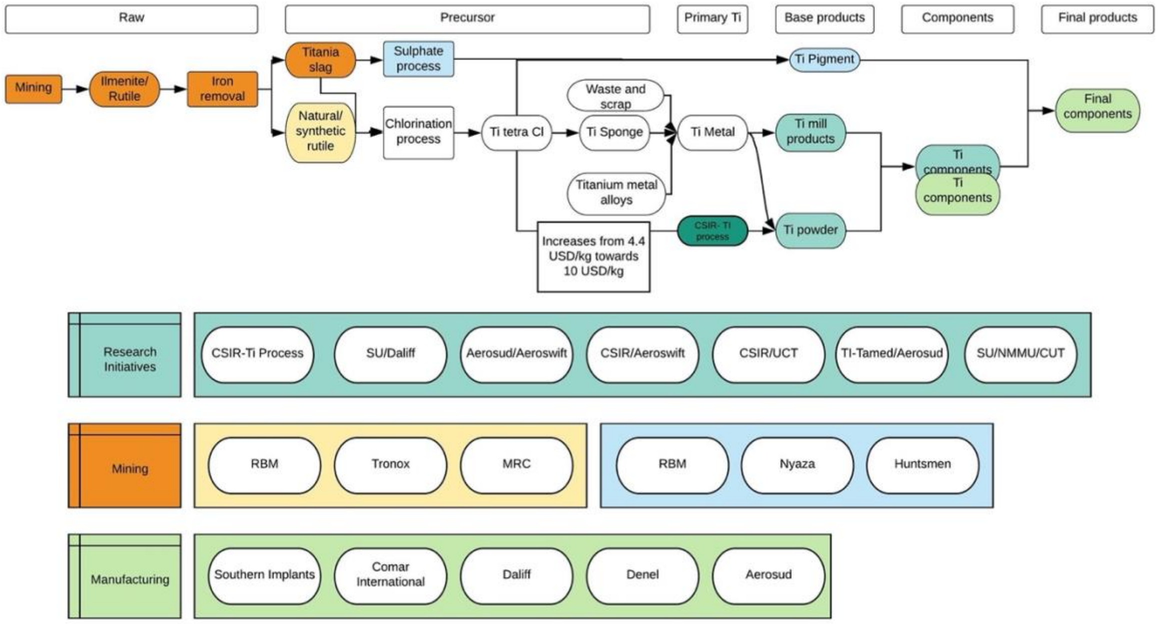

Figure 6.3: Overview of South Africa's current industry involvement

6.5.2. Metrics and activity overlap

In the literature review (Chapter 4) key governmental and non-governmental initiatives and research areas were identified as indicated in Figure 6.3 above. These initiatives can be compared to the identified sectors to determine whether there are any overlaps between the current footprint and optimal results.

The first initiative that has received significant research funding and attention is the collaboration between the TiCoC and the CSIR researching the CSIR-Ti process. This process attempts at producing Ti-powder from Ti-Tetra Cl, thus circumventing the expensive Kroll process. This process utilises products in category 4a and 4b, to produce Ti-powder that can be used to produce numerous Ti components. Category 4 is produced from Ti-Tetra Cl. If this initiative were to be successful, South Africa might also need to invest in producing Ti-Tetra Cl in order to ensure sufficient feedstock for the process. The distance to products in category 4 is relatively low. Although category 4 does not appear in either the complexity maximising or opportunity gain cases, the complexity and opportunity remain above the average. Once this process is established the distance to numerous other components will be significantly reduced.

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Powder alloying can also be expected to become feasible, allowing the production of components for numerous industries such as aerospace and medical.

Aeroswift was a government-backed project created through collaboration between Aerosud and the CSIR investigating the 3D printing of large components. The aim was focused on producing 3D printed titanium aircraft parts that were printed from powder. Currently Aerosud is producing aerospace components from billets, bars and powder. Given Aerosud and Aeroswift's usage of powder, such operations and initiative also stand to benefit if the CSIR-Ti can successfully produce powder of high enough quality. The aerospace components targeted by companies such as Aerosud and Aeroswift are categories 37, 38, and 39. Although none of these categories are in the complexity maximising case, 39 is in the opportunity maximising case. If targeted successfully, categories such as 24 and 32 could more easily be targeted in the future as well. Although the South African aerospace industry is not as established compared to other countries such as the USA and Germany, the suggested long-term benefits of the initiative are evident, as international aerospace companies such as Airbus already source parts of military transport aircraft from the infant titanium industry in South Africa. Ti-Tamed also acts as a development partner for Aerosud aviation. Through turning and milling, they have produced over 181 high-precision engineering parts for Aerosud. These fall primarily under categories 37, 38 and 39. Airbus is also offering consulting advice to Aerosud to ensure commercial success (Wild, 2018).

Various research collaborations between universities such as SU, UCT and VUT have been focusing on the 3D printing of biomedical components and implants. The category targeted through these initiatives is category 45 that has both good complexity and opportunity gain, but with a relatively high distance. Interestingly enough, with a good complexity it does not feature in the complexity maximising case, only in the opportunity gain maximising case. Numerous category combinations are possible with category 45 in the opportunity maximising case. Additional combinations with 45 are (24, 32)/(25, 32)/(32, 39)/(30, 32) or (30, 39). Firms such as Ti-Tamed and Southern Implants are already active in South Africa. Although they currently use billets to produce implants through milling and turning, research by Dalif, Aerosud, SU, CUT and VUT is investigating methods of improved additive manufacturing from powder.

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There is an initiative to establish a viable chlorine plant, producing pigment matter. This targets categories 5 and 6 specifically, with 6 featuring in both complexity and opportunity gain maximising cases and 5 not featuring in any of the cases. The opportunity for category 6 is significant, as it can lead to the production of final products such as ink, print, dyes and plastics. The biggest consumption of titanium is the pigment industry; thus it is perceived as sensible for South Africa to pursue it.

Table 6.8 is an overview of South Africa's current value chain, where South Africa's policy interests are based and how these interests align with the results of the complexity and opportunity maximising case calculations. The key sectors that each policy is targeting, have been identified and comparisons can be drawn on whether these policies align with the results from the complexity and opportunity maximising cases. The analysis involved assessing each of the following indicators:

- Looking at the RCA of each tier into which the product category falls;
- Looking at the economic complexity and opportunity gain each product category offers; and
- The distances of each category, as this will also have an impact in the initial investment required.

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Table 6.8: Current beneficiation plan, sectors targeted and strategic value of sectors

Initiative	Sectors targeted	Strategic value of target sectors
TiCoC: CSIR-Ti Process	2–5 (Primarily 4)	If processes can be successfully established, more sectors can potentially be targeted at lower investment costs.
Aeroswift: CSIR and Aerosud. Ti-Tamed and Aerosud (Governmental and non-governmental).	38, 39	• Low in terms of complexity, but good in terms of opportunity gain. • Long-term investment, as high opportunity can lead to more complex products. • Distances are high thus large initial investment will be required.
Medical additive manufacturing (research collaborations).	45	• Long-term investment as 45 is linked to numerous category combinations in opportunity gain. • Require high initial investment to overcome distance.
New plants (chlorine plants, bushveld titano-magnetite), Nyaza light metals.	5 and 6	• 6 features mainly in complexity maximising case and limited in opportunity gain. • The success of this plant will allow for numerous components in tier 4 to become viable.

Thus, it is evident that the current initiatives are targeting strategically appropriate areas in the titanium value chain through governmental and non-governmental initiatives. In particular, product categories such as 6, 39 and 45 are being investigated by South Africa and feature in either complexity maximising or opportunity gain cases. This can be observed in Figure 6.4 below. From the initial calculations it was suggested that category 30 should be targeted, as this category has the best overall metrics. Thus, analysing the various combinations possible with 30, the following combination were found in the opportunity maximising gain case between 30, 39 and 45 at a distance of 12,85 and relatively good complexity and opportunity gain contributions compared to the rest.

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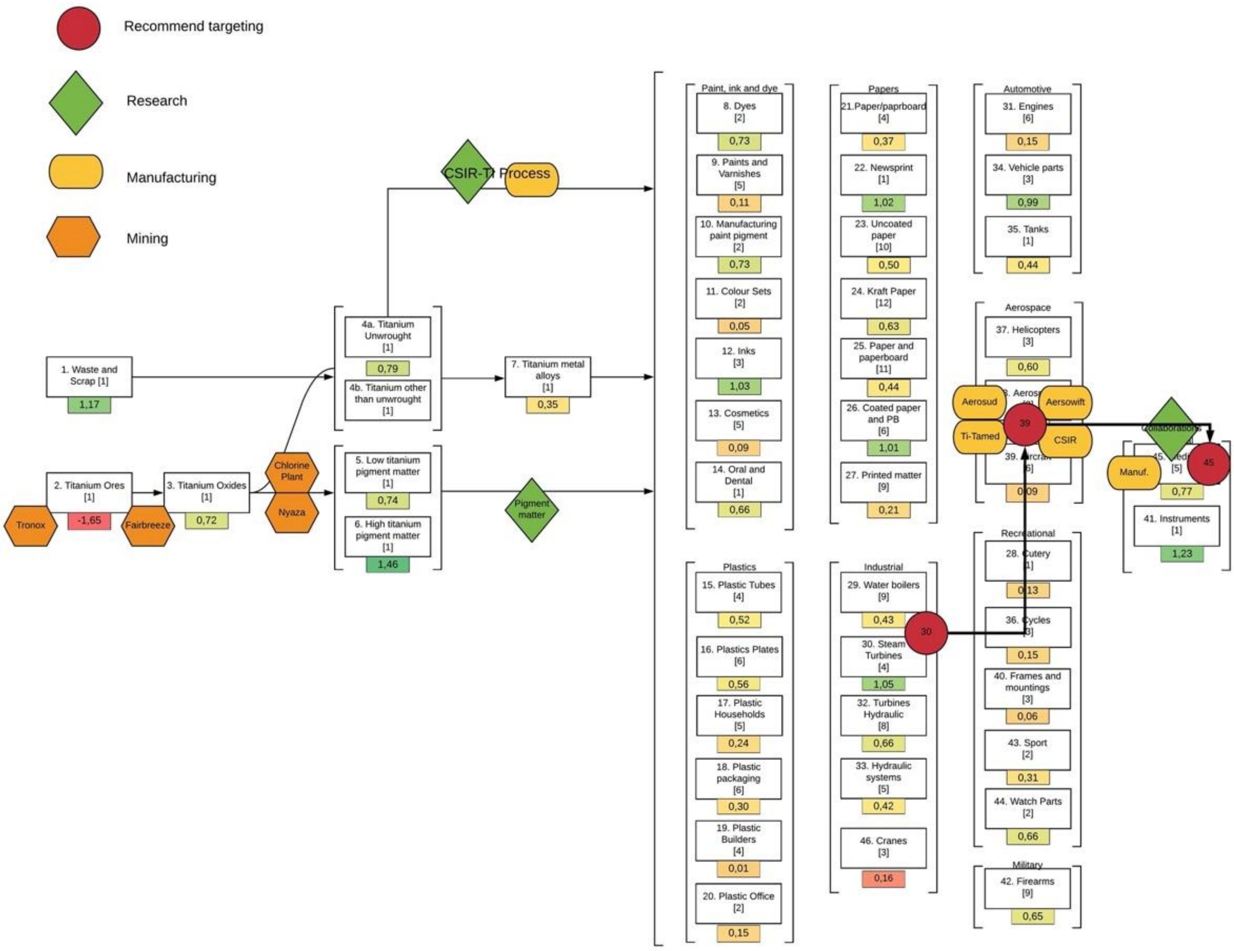

Figure 6.4: Visual display of current footprint and suggested combination to target

Category 39 has an RCA of 0,49 and category 45 an RCA of 0,1 indicating that a bigger footprint exists for category 39. Although there are numerous already ongoing research collaborations between universities for category 45, it qualifies as a viable option to pursue, as it exhibits a higher opportunity gain and lower distance compared with the remaining products in category 39. Thus, following the developmental path as shown in Table 6.9, South Africa must first target category 30, followed by 39 and 45 respectively.

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Table 6.9: Overview of categories in developmental path

Order	Category	RCA	Complexity	Opportunity Gain	Distance
1	30 – Steam Turbines	0,093	0,145	0,837	3,478
2	39 – Aircraft and Spacecraft	0,448	0,017	0,939	5,074
3	45- Dental implants	0,108	0,119	0,945	3,478

Due to the low RCA for both categories 30 and 45 the intervention planning might be obstructed at stages, although with South Africa already having done research and collaborations aligned with 45 it is expected that 45 will have less obstructions. Nonethelss, based on both metrics and the country's current footprint, category 30 appears to be a logical choice as industry on which to focus on for the intervention planning phase of this research.

6.6. Chapter summary

After having mapped out the industry and applying a dynamic analysis on the categories, it was established that categories 30 – Steam turbines and 10 – Paint pigments are deemed strategically fit for South Africa as they represent the metal and pigment industries. Both categories featured in the opportunity gain and complexity maximising cases, at respective distances. From a brief overview it is evident that they do not align completely with South Africa's current production and beneficiation initiatives, therefore the ideal developmental path to be pursued includes categories that align with South Africa's current footprint. The potential developmental path included categories 30, 39 and 45. Based on metrics alone and the fact that category 30 is the first category in an ideal developmental path, category 30 will be assessed for the intervention planning. Even though there are some similarities to explore between the industries, the following phase will pursue discovering the key locational factors that are required to support the industry related to category 30 in South Africa. This will be the foundation the intervention plan for the next two categories can be built upon, if the identified developmental path is to be pursued.

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Chapter 7

Titanium case: Intervention planning for South Africa

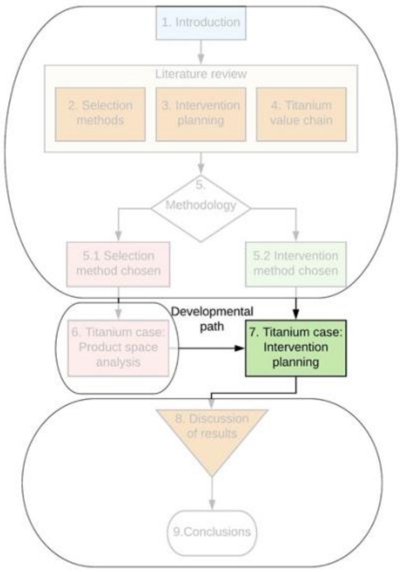

Figure 7.1: Document progress, focus on Chapter 7 – Intervention planning

This chapter discusses the relevant steps involved that were used to guide the intervention planning for the selected titanium category. Section 7.1 clarifies which category identified in Chapter 6 is chosen for intervention planning analysis. Section 7.2 identifies the specific product within the category that the analysis is focused on. The selection is based on various factors, including opportunity gain per distance. Section 7.2 also includes an assessment of the major import and export players in the industry and an overview of South Africa's market share within each sector. Section 7.3 presents the assessment of the market-related dynamics for the identified product winners of the sectors. Section 7.4 presents the location-centric framework's market and location analysis. Section 7.5 presents an assessment of the key factors and provides recommendations for the interventions to focus on. Through the analysis presented in the chapter, various limitations and obstacles were encountered that hampered the accuracy of the intervention planning.

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7.1. Focal category to target

In Section 6.2, product categories 10 and 30 were initially picked as the "winners" due to the numerous advantages and opportunities that each provides. These were subsequently selected as "target categories" within the titanium dioxide and titanium metal side of the value chain. The analysis in this section focuses on the steam turbine industry.

The major inroads in the pigment industry have been made by Nyaza Light Metals, by using waste steel slag and not South Africa's natural titanium base, and with production scheduled to only start in 2020 the inroads are still nascent. The fact that Huntsmen Tioxide already closed down also suggests that the success of the industry is not guaranteed. The steam turbine industry was thus chosen as the first "test case" for the application of the framework after comparisons in Section 6.5 further proved the applicability of the industry for South Africa. The steam turbine industry combined with aircraft and spacecraft (category 39) and medical implants (category 45) created a developmental path that can promote economic growth and is aligned with South Africa's current interests, making it a seemingly ideal category to target.

The reason for only analysing one sector is twofold. The first reason is that the location-centric framework is still a relatively new framework. Hence the application is exploratory. Thus, apart from potentially providing useful guidance for the future industrial policy, the application of the framework also has two aims with regards to the assessment of the framework. Firstly, to identify the strengths and weaknesses of the approach. And secondly, to identify how the approach can be improved in future studies. Given these foci and the time constraints relevant to this study, one case was deemed to be sufficient for the exploratory aim of this part of the research study.

7.2. Assessing the identified category

Although the categories were selected in such a way that the products within each category could be targeted collectively, it is necessary to first identify the individual products to target and determine the industry factors for one product before attempting to target the entire category at once. By successfully targeting one product, it will be easier to move on and achieve

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an RCA > 1 for the other products in the category. The same accounts for the rest of the categories in the developmental path. Hence, Section 7.2.1 evaluates the products within the chosen product category to select the most appropriate initial target. Further to this, Section 7.2.2 provides an initial analysis of the context of the selected product by evaluating the key importers and exporters of the product and South Africa's current contribution to global trade.

7.2.1. Product level metrics

None of the four products within the steam turbine category yet had an RCA > 1, making them all possible options to pursue. Starting with the lowest distance product, the HS product code 840610 is the winner with a distance of 0,8626, marginally better than the other products. The next key performance indicator was opportunity gain where product code 840681 is the best option with an opportunity gain of 0,5155. Analysing complexity reveals product 840681, outperforming the other products with a high complexity value of 2,115. Thus, by dominating most of the key performance indicators, it was decided that product 840681 is the best product to target. Looking at Table 7.1 it can be seen that both 840681 and 840682 are highlighted in green, so it was decided to analyse the two products together, as they are very similar and will thus most probably have the same factors.

Table 7.1: Product category 31 analysis for which product to target

Product	Distance	Opportunity Gain	Complexity	RCA
840610 - Steam and other vapour turbines; for marine propulsion	0,8626	0,2076	0,4085	0
840681 - Turbines steam and vapour, non-marine > 40MW.	0,8806	0,5155	2,1155	0,094
840682 – Turbines steam and vapour, non-marine < 40MW.	0,863	0,3616	0,8565	0,0787
840690 - Parts of steam and vapour turbines.	0,8716	0,2856	0,7997	0,2006

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7.2.2. Industry leaders in demand, supply and their locations

The data shown in Table 7.2 was taken from the OEC database with the purpose of showing the top export and import countries, and to determine South Africa's current industry share and South Africa's current industry partners. More information regarding all the countries South Africa trades with for all three products is shown in Appendix H. From Table 7.2 the top exporter for both products is Japan with Pakistan and Indonesia remaining the top importers for both. Interestingly, for product 840681, Germany is both the biggest import and export partner with South Africa. Looking at the size of the import market, attempts could be made to bring the export market to the same level. Germany is ranked second for import collaborators for product 840682. From a competition perspective Germany is consistently the top performer, and once again South Africa can either compete directly with Germany for market share or allow German enterprises to establish themselves in South Africa. Out of African countries, Nigeria and Tanzania are the biggest markets for South Africa and the country would have to work on ensuring the relationships are maintained in order to grow its market on the continent.

Table 7.2: Top import and export countries internationally and top collaborators with South Africa for products 840681 and 840682 in category 31 (Based on data from the International Trade Centre (www.trademap.org) from 2017)

Category	Import/ Export	Top Country Worldwide	South Africa industry Size	Top trading partner of South Africa
840681 - Turbines steam and vapour, non-marine > 40MW.	Export	Japan	$834 864	Germany
		Germany		Poland
		China		Tanzania
	Import	Vietnam	$234 495 673	Germany
		Pakistan		France
		Indonesia		Thailand
840682 – Turbines steam and vapour, non-marine < 40MW.	Export	Japan	$381 933	India
		China		Nigeria
		USA		Mozambique
	Import	Pakistan	$7 170 396	Netherlands
		Turkey		Germany
		Indonesia		Austria

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7.3. Industry-related background

Due to the competitive nature of the steam turbine industry and the fact that the industry is not as yet well established in South Africa, the collection of industry-related information from industry leaders within South Africa and internationally was difficult to obtain. Thus, instead of the preferred method of interviews with industry players, the analysis had to be based on data from a report by MarketsandMarket™. Based on the report, the following market dynamics were established. The report was generated based on specific enquiries and requests and is not publicly available.

As indicated in the MarketsandMarket™ report on the steam turbine industry, the market is primarily driven by the increasing demand for electricity, which is due to the ever-increasing world population and industrialisation. This instigates investments being made in sectors that can assist in increasing power generation capacities such as steam turbines. The other issue with steam turbines and power generation is that they are heavily dependent on fossil fuels for power generation and with world trends seeking cleaner energy the growth of the industry is uncertain. Thus perhaps another weakness of using the IO-PS on its own is the lack of accounting for future market dynamics and growth. There are opportunities within the market through upgrades and replacements of steam turbine parts. The various opportunites within the supply chain is shown in Figure 7.2 below. High-capital requirements are making it difficult for new businesses to enter, which is evident through the report indicating that the majority of the current industry leaders are gaining market share through establishing partnerships. The intensity of rivalry is very high, with current industry leaders very equal in terms of technological advances, making them very protective over any small advantages. More in-depth descriptions related to market dynamics, industry competitveness and the strategies used to gain market dominance can be found in Appendix I.

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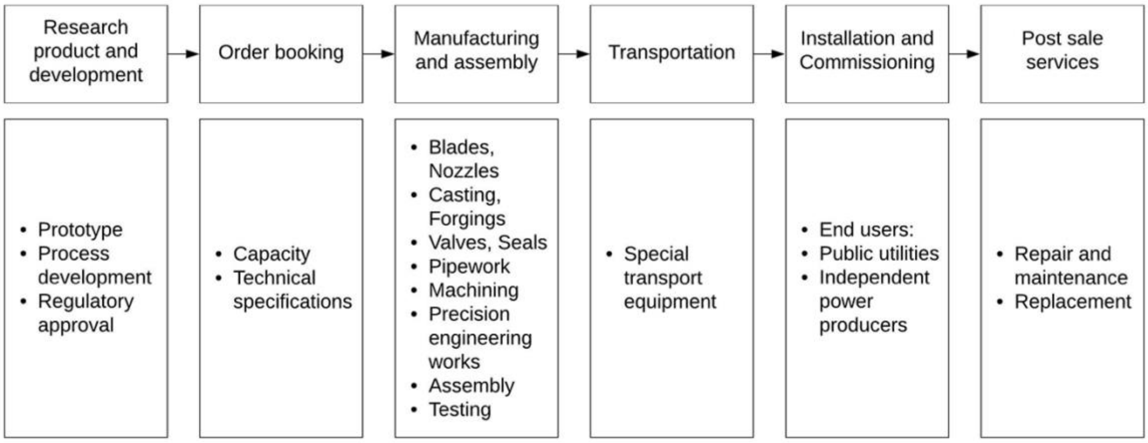

Figure 7.2: Steam turbine supply chain

The big manufacturers such as Alstom SA (France) and Siemens AG (Germany) source components, fixtures and auxiliary equipment from various large, medium and small suppliers. Suppliers are monitored by strict regulations and rated against factors such as quality, capacity, lead times and cost competitiveness. Blades, nozzles etc. are sourced from large manufacturers and are machined and assembled in-house at large manufacturers. Manufacturing only starts after orders have been placed, as capacity and technical requirements determine the manufacturing process and materials required. Specialist companies are in charge of transportation from manufacturing to installation as dedicated trails, heavy rail wagons, barges, ships, gantry cranes, strand jacks and other similar equipment are required. Manufacturers are involved with installations and maintenance services as well. They will carry out periodic checks, repairs and refurbishment of the equipment. There are independent repair and maintenance companies available across the market. Assessing the supply chain, numerous potential opportunities become visible for South Africa, especially in the supply of components.

7.4. Market and location analysis

The following section systematically addresses the analysis identifying the key location-related factors. Due to various constraints and obstacles encountered during the analysis, the in-depth analysis of these phases is shown in Appendix J and not included in the main text, as further validation of the results would be required before any policy decision can be based on the

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analysis. However, the exploratory application of the framework enabled key learnings in terms of the strengths and weaknesses of the approach and preliminary classifications based on the report could be drawn.

During the initial stages of contacting various firms involved in the industry, it became evident that the industry is very protective of its intellectual property and hesitant to provide feedback on the various factors which are potentially allowing them to have the competitive advantage. This was also made difficult because of the small industry size in South Africa. Requests for taking part in the survey were sent out to multiple firms, domestic (4) and international (5). The search was also extended to firms involved in the servicing and maintenance (3) of steam turbines. However, none of the firms were eventually willing to participate in the study. Due to being constrained in term of primary information such as questionnaire feedback from SMEs in the industry, the rating of any determinants had to be inferred based on information from the market report.

The lack of primary information detracted from the study's ability to establish concrete intervention recommendations. It was, however, decided to apply the methodology on the market report to assess the industry. The recommendation of key factors to focus on was based on preliminary findings from the MarketsandMarket™ industry report and relevant literature review sections. This preliminary finding was useful for orientating gaining an initial understanding of the steam turbine industry dynamics and evaluating the usefulness of the framework.

The case study based on the secondary data is presented in Appendix J with the classification and description of factors in Table J.1. During the analysis each factor related to the respective dimensions was discussed and preliminary conclusions were deduced regarding their importance and South Africa's support of the factor.

Based on the preliminary analysis, Tables 7.3 and 7.4 provide the RT and LT quadrants (as discussed in Section 5.2.4) for the steam turbine industry. The use of primary data would allow more detailed prioritisation of the sub-factors related to dimensions 3a, 3b and 3c. Based on these dimensions and quadrants an appropriate intervention strategy could be deduced. An in-depth discussion of each dimension is included in Appendix J. This is illustrative of how the methodology could be applied. Thus, the factors discussed in Table 7.3 (as outlined in Section

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3.4.3), provide an indication of the factors in which South Africa seemed to be performing well. The goal would be to establish interventions in such a way as to not impede or negatively affect these factors.

Table 7.3: Illustrative analysis of factors to focus on for South African intervention to support the steam turbine industry related to the RT quadrant

Dimensions		Factors relating to each dimension	
1	Winning market share	Quality of products	
2	Industry and firm properties	Dynamism of product market environment	
Focal segment		Market Factors	Location Factors
3a	Manufacturing (most important)	Cost	Labour cost and productivity, government policy and regulation
		Lead time	N/A
		Flexibility, responsiveness	Supporting services, institutions and trusts
		Reliability and Quality	Quality inputs, supporting services
		Sustainability	Skills availability, government policy
3b	Research	Responsiveness to leading customer	Skills availability, quality and scale of science and technology
		Improves state of the art	Quality and scale of science and technology as well as availability of cost and assets (starting up costs)
		IP protection	N/A
3c	Developments	Responsiveness to leading customer	Quality and scale of science and technology
		IP protection	N/A

The factors mentioned in Table 7.4 are typically the factors that will require immediate intervention and assessment to validate whether they are actually achievable by South Africa. An analysis should be performed to identify potential reasons why the country is currently not supportive or contributing with regard to these factors and determine whether the country can influence these factors. Starting with the first dimension, cost of product is important from the market side, thus assessment has to be done on where costs can be decreased. Examples can be either supporting the CSIR-Ti process for cheaper raw materials or local processing of final components. Currently, South Africa's capability to support the complexity of the production

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processes involved seems to be lacking but not non-existent, thus an assessment of the processes involved is required to identify improvement opportunities. The analysis can continue for dimension 3 as well, i.e. factors such as demand distance cannot be changed, but effective transport and logistics can be established to counter the lead time and sustainability concerns. The top importing countries are Pakistan and Indonesia as shown in Table 7.2, thus not much can be done towards demand distance, but perhaps effective transportation methods can be established to counter these factors. The high IP protection of the industry is a factor that can be difficult to overcome which can hamper attempts to narrow the gap in industry and product-related knowledge.

Table 7.4: Illustrative analysis of factors to focus on for South African intervention to support the steam turbine industry related to the LT quadrant

Dimensions		Factors relating to each dimension	
1	Winning market share	Cost of product	
2	Industry and firm properties	Complexity of production processes and spill over knowledge employed	
Focal segment		Market Factors	Location Factors
3a	Manufacturing (most important)	Cost	Cost of capital and demand distance, quality inputs
		Lead time	Demand distance, Infrastructure
		Flexibility, responsiveness	Contracting environment
		Reliability and Quality	Demand distance, Institutions and trusts, Infrastructure
		Sustainability	Demand distance
3b	Research	Responsiveness to leading customer	IP regulation
		Improves state of the art	IP regulation
		IP protection	N/A
3c	Developments	Responsiveness to leading customer	Availability and cost of knowledge assets and technology proximity to manufacturing
		IP protection	N/A

Due to the focus being on manufacturing, the initial approach is to target the factors in the manufacturing activity. Knowing where the biggest markets are located will allow the

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assessment of the moderating factors, as it will be the end goal to eventually serve those markets. As seen from the market report and Table 7.2, the top markets are international which introduces a wide range of moderating factors. Thus, the potential effect of transport cost, interaction cost, political factors and trade barriers between South Africa and the various markets can be assessed. Analysing Japan's current industry will provide valuable insight, as they seem to have market dominance, which is evident, as they are the top exporters seen in Table 7.2 and from the background research presented in Section 7.3.

7.5. Intervention recommendations based on preliminary classifications

Through the location-centric framework, the key factors related to the dimensions are shown in Table 7.5 below, and by using the policy characteristics discussed in Section 3.4 and the Table J.2 in Appendix J as guidance, the interventions can be established appropriately. South Africa's current incentives that have been established to assist firms to counter the cross-cutting constraints, as discussed in Section 4.7.1, can also be assessed against the factors. An in-depth discussion regarding the effects of each factor as well as indicating the appropriateness of each sector is applied in Appendix J, although in a limited sense due to the data constraints. The recommendations given below are based on the findings from the review of the market report. Regarding the location-related factors in Table 7.5, those highlighted in green are currently in South Africa's favour providing a good advantage (relating to the RT and RB quadrant in Figure 5.4); those highlighted in yellow are yet to be attained but are attainable for South Africa through accurate interventions (relating to the LT quadrant in Figure 5.4). The orange-highlighted factors are also still to be attained but will be more costly for South Africa to attain or more difficult to enable firms to have high performance level for those factors (relating to the LT quadrant in Figure 5.4).

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Table 7.5: Overview of import factors affecting the three dimensions (primarily focusing on manufacturing)

<table>
<tr><th>Dimension</th><th colspan="2">Factors</th><th colspan="2">Key factors to consider for interventions</th></tr>
<tr><td>1. Winning market share</td><td colspan="2">Cost and quality of products.</td><td colspan="2">Support local research agendas, enabling cost effective local development or manufacturing of quality components. Further support current research and collaborations surrounding category 39 and 45.</td></tr>
<tr><td>2. Industry and firm properties</td><td colspan="2">Complexity of production processes and spill over knowledge.</td><td colspan="2">Develop technical “know-how” knowledge in South Africa, ensuring transfer of knowledge. Achievable through collaborations or merger and acquisitions.</td></tr>
<tr><th colspan="5">Market and location-related factors – Manufacturing segment</th></tr>
<tr><td rowspan="6">3. Manufacturing</td><th>Market Focus</th><th>Importance</th><th>Location-related factors</th><th>Relative performance of South Africa</th></tr>
<tr><td rowspan="2">Cost</td><td rowspan="2">High</td><td>Labour costs, Incentives, Cost of land, Government policy</td><td rowspan="2">Performance is obstructed by factors highlighted in orange.</td></tr>
<tr><td>Cost of capital, Availability and cost of utilities, Exchange rates, Transport costs</td></tr>
<tr><td>Quality and reliability</td><td>High</td><td>Nearness and quality of material inputs, Supporting services, Skills availability, Infrastructure</td><td>Factors can be obtained if targeted strategically, allowing a good performance level.</td></tr>
<tr><td rowspan="2">Lead time</td><td rowspan="2">Low</td><td>Infrastructure</td><td rowspan="2">Limited options to improve performance, focus to be</td></tr>
<tr><td>Demand distance</td></tr>
</table>

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				placed on infrastructure.
	Flexibility and responsiveness	Low	Contract environment, Nearness of quality material inputs Demand distance	Limited options to improve performance, focus to be placed on nearness of quality material inputs.
	Sustainability	Low	Nearness of quality material inputs Demand distance	Limited options to improve performance, focus to be placed on nearness of quality material inputs.
Overall performance.	Focus should be placed on cost related factors as the market value cost related factors as important. If the location related factors are are better supported in South Africa, the potetntial overall performance for firms in South Africa within the steam turbine industry can become highly competitive.			

The first dimension to focus on is the winning of market share. Firstly, the market is seeking quality products, as the efficiency of steam turbines is very important, which is one of the factors for the high costs. If the final components can be produced locally and cost-effectively in South Africa, it will allow for an advantage in winning market share. The DST is advised to invest in the appropriate technologies, research programmes and training facilities to enhance local manufacturing capabilities of the different final components. Further promoting the TCIP and TIA programmes, with refinements towards steam turbines can be of siginifcant benefit. Promoting the industry could also be served by continuing the support of the CSIR in their research regarding the CSIR-Ti process. Total cost of ownership, refer to Appendix B.3, will also have a significant impact, reducing production costs, logistics costs, tariffs and taxes. Referring to Section 6.5.2, South Africa's current footprint with research and collaboration with firms such as Ti-Tamed, Aerosud aviation, Daliff and respective South African universities relating to categories 39 and 45 is of vital importance in developing the manufacturing capabilities and local knowledge required. Investing in the critical infrastructure requirements through the NGP and developing local critical skills with the SETA programme,

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when referring back to the cross-cutting constraints in Table 4.3 in Section 4.7.1 it is evident that South Africa is already focusing on many of these issues.

The second dimension considers South Africa's ability to support the steam turbine industry. The first aspect is the investing in and upgrading of the appropriate infrastructure in terms of manufacturing, transport and research and development facilities allowing South Africa to move more towards the front of the technological frontier and keeping up with industry changes and in the future becoming the driver. Drivers such as efficiency are of high priority for the industry and through cooperation with appropriate research and manufacturing institutions the technology and skills can be developed to achieve this. There are also opportunities to capitalise on, due to the importance of supporting services involving maintaining and the upgrade of old stations with new and more efficient equipment. The development of local know-how is important and emphasis has to be placed on establishing collaborations with universities and research institutes and potential international investment for companies to transfer the knowledge. Referring again to Section 3.2, the promotion of effective collaborations and technology transfers is important for countries not yet at the front of the technological frontier. This will require a constant feed of skilled employees that can be achieved through vocational training programmes (SETA and institutions of higher learning and training). This serves a dual purpose, as it allows for knowledge spillovers and access to those niche markets that are currently out of reach.

The third dimension regarding focuses on manufacturing-related factors for the market requirements is critical to understand. From Table 7.5 it is evident that cost, quality and reliability are important factors for the market and thus the related location factors will have a higher weighted impact on the overall performance level. Assessing the cost implications, there a few key factors that have a high impact on the potential performance level. High initial costs to build and upgrade the required infrastructure and utility costs are high, as these services are inconsistently provided across South Africa. These factors will have to be targeted as strategically and effectively as possible, as these costs can hamper competitiveness. Due to the current geographic position of the market the transport costs in reaching the markets is a factor potentially undermining competitiveness. These factors can be managed through specialised financial services and costing structures for specific industries. Refocusing on the NGP with specifically assisting with transport and utility costs related to the steam turbine industry could be of significant assistance. Refinements within the CIP towards steam turbines will also be

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beneficial for obtaining the appropriate infrastructure to support the industry. The current incentives already attempting to be supportive in local beneficiation and incentive schemes for employment within certain categories are also beneficial for South Africa.

The second important market-related factors are quality and reliability, which can be classified as factors that are more within reach with existing schemes such as NACI, AMTS and the DTI development scheme being of great value. Included in these are location-related factors such as nearness and quality of material inputs (the DMR is attempting to ensure that raw materials are accessible for local firms through the MPRDA and Mining Charter). Another factor is supporting services and skills availability, including appropriate training programmes, collaborations and facilities subsidised to be subsidised by departments such as DTI with their development scheme. Other contributors could be investing in the appropriate infrastructure and growing the local supply chain footprint for increased nearness of inputs and supportive services. If pursed accurately these factors could support affordable and quality products contributing to high performance levels for firms.

Although rated as not important, the remaining market factors such as lead time, flexibility, responsiveness and sustainability still need to be executed. These factors might not give a firm a highly competitive advantage, yet their absence can still have a significant negative impact on the overall performance. Lead time can be decreased through effective infrastructure and investing in local manufacturing of more parts in supply chain (decrease other parts' demand distance and in effect, lead time). Referring to Section 3.2 it is important for the supply chain to allow resilience and flexibility, and ensuring policies are aligned with charateristics surrounding South Africa's economy. This implies assessing where South Africa is placed on the technological frontier, South Afrca's stand on raw-material endowments, the geographic factors at play and quality of the institiutions. Appropriately addressing the charaterisitics can improve the supply chain resilience and flexibility. Limiting the potential changes from buyers through contractual agreements will allow for higher quality control execution as just-in-time and lean programmes can be planned more accurately. The last factor is to assess the sustainability of manufacturing steam turbines. The government, specifically DMR and DTI, as mentioned before, should seek to have locally produced high quality inputs for suppliers, allowing them affordable access to locally priced raw materials. Sourcing locally could not only reduce transport and increase sustainability, but also increase the total developmental impact of the industry being focused on. The Preferaential Procurement Policy Act, as mention

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in Section 4.7.1, should be focused on with the aim of assisting local processing of raw minerals ensuring numerous components can be manufacturedmore cost effectively.

7.6. Chapter summary

The chapter started off by identifying specific products within the steam turbine sector to target, based on their superior KPIs. The respective industry leaders and South Africa's market share with their respective collaborators was identified. The next phase in this chapter, Section 7.2, briefly discussed the background related to the industry being targeted. Moving on towards Section 7.3, numerous obstacles were faced during the evaluation of key factors related to the market and the location of the industry, preventing an accurate analysis and recommendations being provided. The methodology was still executed with the respective steps and results to be found in Appendix J. Based on the preliminary results, the key factors for South Africa to be successful in the identified industry were identified and classified according to the dimensions that guided the intervention planning.

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Chapter 8

Titanium case: Discussion of results

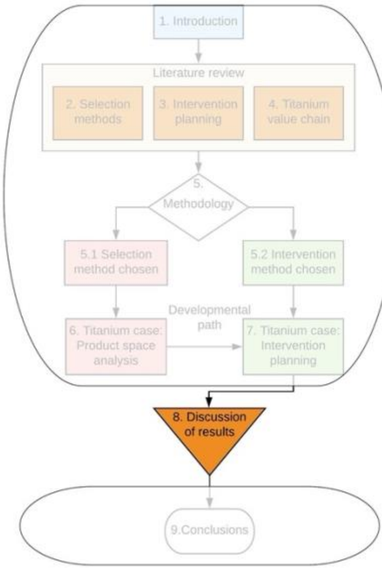

Figure 8.1: Document progress, focus on Chapter 8 – discussion of results

This chapter discusses the results obtained from the analysis executed in Chapter 6 and Chapter 7. The purpose of Section 8.1 is to provide an overview of the key sectors identified to target as well as the respective key locational factors that should be focused on. Section 8.1 also provides an overview of the current collaborations and the industry footprint which can assist in the successful attainment of the key locational factors. Section 8.2 reflects on the approach and discusses the numerous limitations that were faced.

8.1. Overview of findings

The detailed discussion of each category, dimension and related factors shown in Table 8.1 has been discussed in Chapters 6 and 7 respectively; Table 8.1 serves to provide an overview of the findings.

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Table 8.1: Overview of developmental path, product categories and key factors affecting the dimensions and the current footprint of categories in the developmental path

<table>
<tr><th colspan="5">Chosen developmental path</th></tr>
<tr><td>Category</td><td>RCA</td><td>Complexity</td><td>Opportunity Gain</td><td>Distance</td></tr>
<tr><td>30</td><td>0,09</td><td>0,15</td><td>0,84</td><td>3,48</td></tr>
<tr><td>39</td><td>0,45</td><td>0,02</td><td>0,94</td><td>5,07</td></tr>
<tr><td>45</td><td>0,11</td><td>0,12</td><td>0,98</td><td>4,39</td></tr>
<tr><td colspan="2">Overall</td><td>0,21</td><td>2,96</td><td>12,85</td></tr>
<tr><th colspan="5">Intervention focal points for category 30</th></tr>
<tr><td>Dimension</td><td colspan="2">Important Factors</td><td colspan="2">Interventions and location-related factors</td></tr>
<tr><td>1</td><td colspan="2">Cost and Quality</td><td colspan="2">Focus on local manufacturing and quality of processes (CSIR-Ti process, research collaborations between firms, research centres and universities, NGP, CIP).</td></tr>
<tr><td>2</td><td colspan="2">Complexity and local knowledge</td><td colspan="2">Collaborations and technical training programmes (SETA, NGP, TIA, TICP).</td></tr>
<tr><td>3</td><td colspan="2">Manufacturing (cost)</td><td colspan="2">Cost of capital (financing), cost of utilities and transport costs.</td></tr>
<tr><th colspan="5">South Africa’s footprint</th></tr>
<tr><td>Industry</td><td colspan="4">Ti-Tamed being a developmental partner for Aerosud, Aeroswift project, Denel, Daliff, CSIR are all projects currently being driven in South Africa.</td></tr>
<tr><td>Research</td><td colspan="4">Aeroswift project between Aerosud and CSIR - 3D printing of large components. Universities and research centres to continue research on 3D printing of medical implants and additive manufacturing.</td></tr>
</table>

The approach that was followed selected categories that were more suited towards South Africa’s current footprint, offering solutions that have strategic benefits and that are numerically appropriate to target. The approach searched for combinations that included categories close to optimal values and categories aligned with South Africa’s footprint.

Table 8.1 provides a broad overview of the results from Chapters 6 and 7, aiming at providing a final summary of the categories, factors and focus areas for new interventions or established interventions that should be focused on more thoroughly. The ideal category to target was category 30, due to its superior values and due to the fact that if further developments are deemed fit, there are categories such as 39 and 45 that form part of the developmental path and are aligned with South Africa’s current footprint. Table 8.1 also highlights the intervention focal points for category 30, which current programmes are in place to assist with the focal points and what the underlying focal area should be. Lastly, Table 8.1 provides a brief overview

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of the overlapping firms (industries), research collaborations and locational factors between categories 30, 39 and 45, indicating the potential support structures and minor refinements to respective interventions required if all three categories are to be targeted.

8.2. Reflection on approach

After the completion of the study, a number of strengths and weaknesses of the chosen methodology could be identified. These relate both to the use of the IO-PS, the location-centric framework and the development of the subsequent recommendations.

The initial aim of using the two methods (selection and intervention planning) in succession was to exploit the complementary characteristics each has to offer. The first method was predominantly quantitative and aimed at identifying the most optimal sectors to target. The second method assessed the viability of a particular opportunity, through evaluating the key factors identified during the intervention analysis that will have to be addressed for the industry to be a success. The two-phased approach was believed to provide a good combination between quantitative and qualitative assessment of an industry. The first phase allowed the identification of sectors relatively close to South Africa's current productive structure, but for which South Africa does not yet have an RCA. The strength of this method was that it allowed a rapid assessment of the numerous sectors related to a value chain and based on these metrics, key conclusions could be drawn. Conclusions such as the potential costs of pursuing such an industry, the economic benefits and potential growth from the industry could be identified at first glance. The IO-PS analysis was enhanced by assessing South Africa's current footprint in the industry against what the complexity and opportunity maximising solutions suggested. A developmental path was chosen not just based on optimal metrics but also based on its alignment with South Africa's current initiatives and footprint in the industry.

In terms of the IO-PS, the nature of the IO-PS is to assess distance, opportunity gain and complexity values and these metrics were used to identify categories for which South Africa does not yet have an RCA. Even if a category has a large distance, implying that it is far away from the current productive structure, it could still be selected if the opportunity gain is very high as the category will have a good ratio. This can lead to blindly choosing categories, such as 30, for which there is limited information for South Africa, as there is no current footprint

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for this category in the country. Local industry experts are difficult to find and international experts who can provide assistance with market information do not have in-depth knowledge of the South African situation. These constraints were difficult to anticipate during the IO-PS analysis; the best indicator that might provide information in this regard is the category's RCA value. However, this would not be a perfect indicator of this risk as industries will also vary in terms of their openness. Furthermore, given the information gleaned from the location-centric analysis, a probability exists that the market is not reachable or that the market is potentially not worth pursuing. Although this conclusion cannot be drawn based only on secondary information, the mere possibility of this reality also highlights the potential risk of using the IO-PS as the sole industry selection approach.

A second limitation in relation to the IO-PS, is that the methodology does not consider the trajectory of industries. For example, the products of the chosen industry from the IO-PS metrics, is primarily relevant to the electricity generation industry making use of fossil fuels. However, the increasing importance of renewable energy could undermine the growth of this industry in the longer run. Yet, the IO-PS provides no indication of this type of risk.

The second phase was deemed well-suited to assess the key market and location factors related to the industry. Various key factors that drive market dominance and leading performances in the industry were sought to be identified to allow countries such as South Africa to assess what is required from them to support the industry and to determine whether it is a realistic opportunity or not.

The main drawback of the location-centric analysis was that the sector being targeted was not one for which the country did not yet have an RCA, implying these industries are not well established within the country. This meant that it was difficult to establish the impact of each factor related to the performance of the industry as well as to get valuable feedback from the industry itself. Due to the country not yet having an RCA, there were limited industry experts to consult. The industry selected was also protective regarding its intellectual properties, further complicating information gathering. The application was thus severely hampered and an alternative method for such as a case study based on a market report had to be used. The key factors identified affecting the dimensions were only presented for illustrative purposes, as the accurate rating of each factor was questionable.

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During the intervention analysis phase, the main limitation was that recommendations were based on secondary data that allowed for various misinterpretations and biased opinions to hamper the analysis during the case study. It also limited the prioritisation of the multiple factors related to each dimension. Although the market report provided an overview and key insights could be drawn, there were still opportunities for making biased ratings. Nonetheless, the analysis did allow for a partial execution of the respective frameworks, which was deemed useful for this study's purposes.

8.3. Chapter summary

The chapter provided an overview of the key findings from the IO-PS and location-centric frameworks. The categories in the developmental path and the dimensions with the respective locational factors were discussed. Key insights, such as value of collaborations and technical knowledge and who to collaborate with was discovered. Important location factors related to costs will require more precise focus and interventions to attain. The chapter continued discussing the strengths and weaknesses of using the two frameworks in conjunction to attain the aim of the study.

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Chapter 9

Conclusion

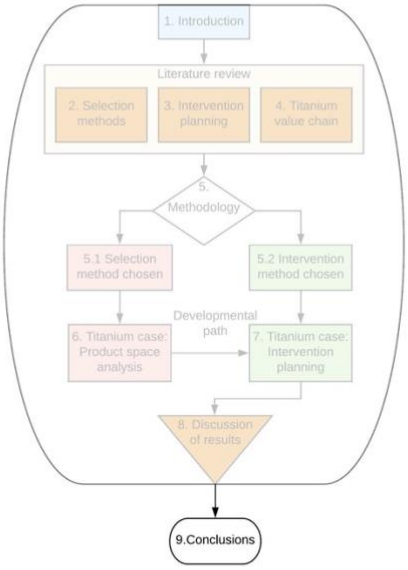

Figure 9.1: Document progress, focus on Chapter 9 – focusing on conclusion

Section 9.1 summarises the research and how each objective was addressed. Section 9.2 provides recommendations based on the results and obstacles faced during the research. Section 9.3 discusses the contribution the research made towards the field of study with Section 9.4 discussing the limitations of the research. The chapter concludes with Section 9.5 providing recommendations for future work based on the work done in this study.

9.1. Summary

The research aimed to find areas within the titanium value chain, which, if pursued correctly, can be beneficial for South Africa towards growing its productive structure and potentially growing the country's economy. Thus, Chapter 2 provided an extensive literature review on existing methods of analysis. Subsequently, the method that was deemed the most appropriate – a input-output product space analysis approach – was chosen for the research's target identification phase. In Chapter 3 various methods for targeting identified parts of an industry were evaluated with the location-centric framework being selected as the best aligned to the

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objectives of the study. Chapter 4 provided an extensive analysis of the titanium industry's value chain and South Africa's current footprint in the industry. As expected, South Africa, even though having an abundant amount of natural reserves, has a dispersed footprint further down the value chain compared to other international players. Chapter 5 described how the two analysis methods were leveraged to complement each other.

Chapter 6 presented the results of the application of the IO-PS to the titanium industry in South Africa. The results suggested that a mixture of products in the metal industry and products in the pigment industry hold particular potential. After refining the results and based on certain key indicators such as complexity and opportunity gain per distance (as these indicators represent the potential cost and difficulty in obtaining the required knowledge and potential opportunities that can arise), it appeared that the steam turbine industry is the best industry to pursue. It was deemed fit to choose a developmental path with the remaining categories closely aligned to South Africa's current footprint. This led to the selection of aircraft and spacecraft parts as the second category and medical implants for the third category, which are industries that promise both economic growth and appear to be in alignment of the country's current interests. Chapter 7 executed the location-centric framework to grasp what the key factors are that allow this industry to be thriving within certain locations. The location-centric framework's execution had limited success, as numerous obstacles came to light. The success was limited due to the lack of feedback and participation from industry players. Although it was first viewed as an obstacle, the obstacles themselves revealed a considerable amount regarding the focal industry and enabled new insights regarding the application of the two analysis methods. In particular, although the turbine industry seems attractive, it is dominated by a few monopoly players and entering such an industry will require more effort and capital than only gaining the productive knowledge as initially thought. Thus, it might be more viable to directly target the other industries identified without first attaining the focal industry.

Chapter 8 concluded with an overview of the key findings and a reflection on the chosen approaches' strengths and weaknesses. Finally, this chapter provides recommendations, highlights the contribution and limitations of the research and provides suggestions for future work.

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9.2. Contribution of the research

The study makes a contribution through assessing the benefits and viability of the beneficiation of minerals within their country of extraction or origin. Furthermore, it further tested the application of the IO-PS framework, this time on the South African titanium industry. The study also went further by attempting to establish how the identified sectors can be targeted as strategically as possible through applying a location-centric framework. It is the first time that the IO-PS framework has been used in combination with the location-centric analysis framework. This resulted in numerous key discoveries that improved the understanding of the titanium value chain both internationally and in South Africa and the industry dynamics related to products such as steam turbines. A deeper appreciation of the benefits and drawbacks of the using the location-centric analysis framework were also discovered.

The research also allows a clear understanding of the titanium value chain and which parts are within reach of South Africa's productive structure. The research made it evident that although some products might seem near perfect to pursue from a product space perspective, the products might not always be the best option and further analysis is required as was evident with the steam turbine industry. It also allows for further understanding as to why certain industries are only successful in certain regions and whether or not it will be possible to replicate those conditions in a country such as South Africa.

9.3. Limitations of the research

As the research progressed, different limitations were encountered at different stages of the study. The first limitation was experienced during the initial value chain mapping of titanium, where the depth and variety of titanium-related products made it difficult to trace the exact extent to which products are related to titanium. It was challenging to establish the extent to which products are related to titanium dioxide. Through numerous re-runs and cross-checking, a finalised list was used for the final run, although it cannot be guaranteed that all relevant products were included.

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The second limitation was to determine the exact list of locational factors relevant to the research and to get accurate feedback on the factors. The lack of accurate feedback was exacerbated by a combination of companies being very protective of their intellectual property and others stating they only provide service functions and are not involved in the actual manufacturing. This affected the accurate prioritisation of the factors that policies should be focused on. The lack of industry experts and partners made the final analysis of the study very difficult. The last limitation is related to assessing the exact extent of the impact of key locational factors. Knowing exactly what the specifics for infrastructure requirements are or the domain of the cost of utilities-related factors would be necessary to truly uncover the key competitiveness drivers. It is thus recommended that more specific research should be executed for each factor related to the industry.

9.4. Future work

Future work includes addressing the shortcomings in the study itself and continued research on the titanium industry to grow South Africa's knowledge base. Immediate future work includes refining the evaluation method used and applying the method comprehensively on the entire developmental path and not only the first category. This will allow a more in-depth understanding of the key locational factors shared between the numerous industries involved, enabling the collective targeting of common factors. The three dimensions used to guide the intervention planning can also be further developed and refined by assessing the applicability and validity of the factors.

The methodology can also be enhanced by evaluating the selected industries further with tools such as global value chain analysis. Systematically addressing the various activities and stakeholders involved in a global supply chain can potentially enable a better understanding of the dynamics shaping the relevant global value chains and how they can be influenced. The key locational factors identified as most important for supporting an industry will require the cooperation of various actors that will implement, execute and maintain the various key factors to support the new industries.

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Appendix A

Decision methods classification

Table A.1: Classification by methods and tools for supporting decision-making of the 38 papers reviewed by (Gonzalez et al., 2015) (Permission obtained from Elsevier for re-use in a thesis, licence number 4699240711967)

Author	Title	Optimisation models	Simulation and heuristics	Multi-criteria decision analytical approaches: ANP, AHP, DEA	Individual LCA-based	Integrated LCA-based	Soft O.R-based techniques
Abdulrahman, Subramanian, Liu and Chiu	Viability of remanufacturing practice: a strategic decision-making framework for Chinese auto-parts companies.			x			
Arafat, Jijakli and Ahsan	Environmental performance and energy recovery potential of five processes for municipal solid-waste treatment.				x		
Aras, Korugan, Büyüko€zkan, S¸erifog!lu, Erol and Veliog!lu	Locating recycling facilities for IT-based electronic waste in Turkey	x					
Camacho-Vallejo, Gonzalez-Rodríguez, Almaguer and Gonzalez-Ramírez	A Bi-level optimisation model for aid distribution after the occurrence of a disaster.	x					
Chandran, Hoppe, De Vries and Gorgiadou	Conflicting policy beliefs and informational complexities in designing a trans-boundary enforcement monitoring system						x
Fikar and Hirsch	A metaheuristic for routing real-world home service transport systems facilitating walking		x				
Golinska, Kosacka, Mierzwiak and Werner-Lewandowska	Grey decision-making as a tool for the classification of the sustainability level of remanufacturing companies			x			
Guerrero-Baena, Gomez-Limon and Fruet	A multi-criteria method for environmental management system selection: an intellectual capital approach			x			
Janeiro and Patel	Choosing sustainable technologies. Implications of the underlying sustainability paradigm in the decision-making process						x
Jawad, Jaber and Bonney	The economic order quantity model revisited: an extended energy accounting approach	x					
Kundu, SenGupta, Hashim and Redzwan	Taguchi optimization approach for production of activated carbon from phosphoric acid impregnated palm kernel shell by microwave heating		x				
Lam and Lai	Developing environmental sustainability by ANP-QFD approach: the case of shipping operations			x			

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Lambrecht and Thiben	Enhancing sustainable production by the combined use of material flow analysis and mathematical programming.	x					
Liu, Dang, Li, Lian, Evans and Yin	Production planning of multi-stage multi-option Seru production systems with sustainable measures.	x					
Liu, Xie and Liu	A method for predicting the energy consumption of the main driving system of a machine tool in a machining process.	x					
Luo, Huang and Zhang	Energy cost optimal operation of belt conveyors using model predictive control methodology	x					
Madan, Mani, Lee and Lyons	Energy performance evaluation and improvement of unit-manufacturing processes: injection moulding case study						x
Martin	Incorporating values into sustainability decision-making						x
Moreira, Santa-Eulalia, Aït-Kadi and Wang	A conceptual framework to develop green textiles in the aeronautic completion industry: a case study in a large manufacturing company						x
Mota, Gomes, Carvalho and Barbosa-Povoa	Towards supply chain sustainability: economic, environmental and social design and planning	x					
Munisamy and Arabi	Eco-efficiency change in power plants: using a slack-based measure for the Meta-Frontier Malmquist Luenberger productivity index			x			
Neshat and Amin-Naseri	Cleaner power generation through market-driven generation expansion planning: an agent-based hybrid framework of game theory and particle swarm optimisation	x					
O'Driscoll, Kelly and O'Donnell	Intelligent energy-based status identification as a platform for improvement of machine tool efficiency and effectiveness		x				
Paraskevas, Kellens, Dewulf and Duflou	Environmental modelling of aluminium recycling: a life cycle assessment tool for sustainable metal management	x					
Poplawska, Labib, Reed and Ishizaka	A dynamic framework for stakeholder identification and salience measurement using fuzzy logic methodology applied to a corporate social responsibility case study		x				
Qiang	The closed-loop supply chain network with competition and design for remanufacturability	x					
Rahman, Hagare and Maheshwari	Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: an application of Bayesian belief network.		x				
Rashidi, Shabani and Farzipoor Saen	Using data envelopment analysis for estimating energy saving and undesirable output abatement: a case study in the OECD countries			x			
Rosa and Beloborodko	A decision support method for development of industrial synergies: case studies of Latvian brewery and wood-processing industries						x
Seddighi and Ahmadi-Javid	A sustainable risk-averse approach to power generation planning with disruption risk and social responsibility considerations	x					
Sevigne, Gasol, Rieradevall and Gabarrell	Methodology of supporting decision-making of waste management with MFA and CLCA: case study of paper and board recycling					x	

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Souza, Salhofer, Rosenhead, Valle and Estellita Lins	Definition of sustainability impact categories based on stakeholder perspectives					x	
Sproedt, Plehn, Scho€nsleben and Herrmann	A simulation-based decision support for eco-efficiency improvements in production systems		x				
Tajbakhsh and Hassini Wei	A data envelopment analysis approach to evaluate sustainability in supply chain networks			x			
Zhao and Li	Price-and-warranty period decisions for complementary products with horizontal firms' cooperation/non-cooperation strategies	x					
Yilmaz, Anctil and Karanfil	LCA as a decision support tool for evaluation of best available techniques (BATs) for cleaner production of iron casting				x		
Zhang and Haapala	Integrating sustainable manufacturing assessment into decision making for a production work cell			x			
Zhu, Lujia, Mayyas, Omar, Al-Hammadi and Al Saleh	Production energy optimisation using low-dynamic programming, a decision support tool for sustainable manufacturing	x					

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Appendix B

Location-related factors

B.1. Country differentiation and appropriate policies

Table B.1: A matrix representation of country differentiation and 'appropriate industrial policy' sourced from Landesmann and Stöllinger (2018) (aspects potentially most relevant to the South African context are highlighted in green) (Permission to re-use in thesis was obtained from Elsevier, licence number 4699240711967)

Characteristics		Policy Areas				
		Technology Policy	**Labour/Human Capital**	**Finance**	**Industry/Competition**	**Infrastructure**
Technology/ Productivity Level	**High**	Internationally connected innovation system.	High-level STI personnel, research centres; life-long learning	Venture capital finance	Incumbents need to be challenged: encourage new entrants	International connectivity
	Middle	Spillovers to domestic capabilities	Vocational training, international and national mobility	Support for domestic new entrants: bank-based finance	Cluster policy; importance of FDI and spillover	Link up with IPNs: Transport and communications
	Low	Absorption capacity building	Generalised literacy; vocational training: counter-act dramatic brain drains	Development banks: longer-term financing facilities	Attract both MNCs and support spillovers	Improve national, regional and international connectivity
Country size	**Big**	Diversified innovation activity	Wide-ranging human capital buildup	Rely on diversified financing institutions	Avoid concentration of new incumbents	Intra-country and international connectivity
	Middle	Emphasise international inter-linkages	Inter-leafing with international expertise	Foreign banks complemented with domestic financing institutions	Mix of strong domestic companies and entrants	Diversify to territorially spread connectivity centres
	Small	Specialised areas of technology expertise	Importance of complementary of foreign and domestic expertise	Focus finance on bottlenecks for domestic development needs	Some focus on build-up of a small set of large companies permissible	Regional inter-connectivity important
	Rich	Build up know-how in processing stages; diversify in	Training personnel to support up-grade and diversification.	Avoid collusion of financial institutions in rent collections	Strict monitoring of pricing, investment and up-grading plans	Support transport and sourcing links

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Raw Material Based		neighbouring industrial fields				
	Low	R&D support focused on sectors in which technology and skills development are high	Create niche 'tasks' of comparative advantage based on labour resources and skills	Promote build-up of sector-specific financing know-how: specific agencies	Allow entry/exit in established and new fields of C.A.; develop strongholds in some tradeable industries	
Geographic Location (i)	**Land-locked**		International mobility should be strongly encouraged; however, support 'return' schemes to avoid 'brain drain'	Encourage openness to foreign banks.	Specialisation in fields with relatively low physical transport cost	Transport and communication infrastructure essential
	Sea-access		Tailor vocational training and higher education to needs of locational C.A. industries.	Liberalised financial services sector could complement C.A. in trading and other service activities		Exploit locational C.A. industries including relayed service activities
Geographic Location (ii)	**Near HI markets**	Interact in technology fields depending on built-up capabilities	Frequent training, research stays in HI; encourage 'brain circulation' schemes	Keep some domestic complementary finance capability	Carefully focus on fields of specialisation and (cross-border) integration; exploit locational C.A. industries	Facilitate cross-border linkages
	Far HI markets	Use channels of interaction: FDI, researcher mobility, etc.	Build up longer-term training & research collaborations; tailor vocational training and higher education to needs of C.A. industries	Encourage international finance linkages	Encourage linkages: EPZs, IPNs	International connectivity important
Political economy: Institutional/legal standards	**Low**	Try to insulate specialised areas from low legal, institutional standards.	Build up meritocratic, well-resourced special training and educational institutions	Greater power to regulatory and supervisor bodies' external monitoring agencies.	Improve monitoring by competition authority and widen its powers	Specific supervision of infrastructure projects; with assistance of foreign donors
	Medium	Apply above legal protection to a range of prioritised innovation fields.	Ensure funding for diverse higher quality educational & training institutions	General tightening of regulatory and supervisory mechanisms	Transparent scrutiny of public enterprise accounting and performance	Strengthen monitoring, execution and auditing of infrastructure projects

Note: STI=Science, Technology and Innovation; HI=High Income; MNC=Multinational companies; IPN=International Production Network; C.A. Comparative Advantage; EPZ= export processing zones.

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B.2. Factors affecting downstream processing

There have been studies that have identified factors likely to affect the location of the downstream processing of minerals that are more insightful than those provided by linkage theory. Firstly, there are elements related to technical and economic factors such as capital, skilled labour, raw materials, complementary inputs, energy, economies of scale, growth in demand, technological change, proximity to export markets and transport costs. Secondly, structural elements such as financial sources, technological sources, trade and investment and taxation policies have an impact on the initial ease of processing minerals. These two categories were first defined in a study, *'Mineral Processing in Developing Nations*' by the United Nations (United Nations, 1984). Although the study identifies the various factors, it still has the shortcoming of not determining the importance of each factor to downstream processing or establishing a connection between each factor and economic location theory.

De Bruyne (2006) divided the various economic factors that can potentially influence the location of firms (which inadvertently affects the downstream processing of minerals) into two categories. In Table B.2 in the left-hand column is the first category that is classified as first nature (neo-classical trade theories) and the second category in the right-hand column is second nature (new economic geography theories) that has been derived from economic geography models (see Holmes, Fujita, Krugman & Venables, 1999). First nature factors directly determine the location of firms, and, as these factors will be directly involved in the costs of production, these factors have a direct influence on production processes. Second-nature forces induce the snowballing effect, meaning that questions arise such as to how rapidly new producers enter a market or how rapidly the market will grow. Government policies can intervene to increase or counteract the effects of these factors. The degree to which they can interact depends on the key factors that are relevant to the specific region, industry, resources and power available at their disposal (Bam and De Bruyne, 2017).

Table B.2: The economic location determinants of firms (Source: De Bruyne, 2006)

First Nature (Neoclassical Trade Theories)	**Second Nature (New Economic Geography Theories)**
(1) Endowments of factors of production A. Labour B. Capital C. Technology D. Raw Materials E. Energy	(1) Presence of intermediate suppliers (2) Size of final market (3) Transport cost that determines the distance to suppliers/final market.

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(2) Geography of country (e.g. landlocked or not)	

Overman (2006), define three types of interventions that governments and policymakers can pursue to affect the location's outcomes namely:

- government intervention in the form of taxes and levies;
- government investment in infrastructure, technology and education and
- trade policy.

A profound understanding of location determinants is essential to determine the appropriate policy measures to influence the key location factors at play for a particular industry (Bam and De Bruyne, 2017).

B.3. Supplier selection

In most cases the selection of suppliers can have a remarkable effect on the success of the supply chain, and therefore companies place great emphasis on making the correct decisions. The most appropriate suppliers can lead to higher quality products at lower costs while achieving higher customer satisfaction (Chan et al., 2008). Chan et al. (2008) also pointed out that, apart from the two main factors, cost and quality, other factors such as the political economic situation, geographic location, infrastructure, financial background, performance history and risk factors can also be considered as important aspects when selecting suppliers. Supplier selection is a strategic decision for an organisation, as it can maximise the overall value of the organisation, reduce the product supply risk, and maximise the customer satisfaction level. Firms operating internationally search globally for business partners that can supply their required inputs. Through accurate intervention planning, South Africa can showcase that the country has the capability to support international companies and allow them to invest in South Africa's titanium industry and in turn allow South Africa to move downstream in the titanium value chain and start producing finished goods. It is important to investigate the key factors involved, as it will allow the intervention planning to accurately prioritise the key factors. Thus, the policies can target the key areas that will assist South Africa to having better insight as to how they can attract local or foreign direct investments towards the industry as the ideal environment for success. This is important for South Africa to understand and to be aware of these factors because suppliers can serve as sources of competitive advantage for international companies (Simpson, Siguaw and White, 2002).

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There are basically two stages of supplier selection, the first being to establish the decision variables and the second establishing the specific decision-making techniques that will be used to analyse the alternatives. Many decision-making frameworks in the literature have focused on particular geographies or local suppliers whilst not much attention has been given to international suppliers. In Table B.3 some of the most relevant research papers in supplier selection are presented. The table illustrates that there is an overlap between the approaches previously mentioned in Chapter 2.2, as both deal with choosing the best option taking into account various factors and implications.

Table B.3: Past studies on supplier selection approaches (Chan et al., 2008)

Category	Classification	Authors
Review papers	Decision variables and Supplier selection problem	(Dickson, 1966; Current, Benton and Weber, 1991; Weber and Ellram, 1993; De Boer, Van Der Wegen and Telgen, 1998)
Supplier Selection approaches	Weighted-point method	(Timmerman, 1987)
	Matrix approach	(Gregory, 1986)
	Analytical hierarchy process (AHP)	(Nydick and Hill, 1992; Yahya and Kingsman, 1999; Chan and Chan, 2004)
	Integration of AHP and linear programming	(Ghodsypour and O'Brien, 1998)
	Case-based reasoning	(Choy and Lee, 2002)
	Goal programming	(Buffa and Jackson, 1983)
	Integration of AHP and pre-emptive programming	(Wang, Huang and Dismukes, 2004)
	Data development analysis	(Liu, Ding and Lall, 2000)
	Multi-attribute utility approach	(Min, 1994)
	Multi-objective programming	(Weber and Ellram, 1993; Ghodsypour and O'Brien, 1998; Feng, Wang and Wang, 2001)

As the goal is to determine the various factors that affect a location's ability to support a certain economic activity, it remains of great value to grasp the context surrounding the decision variables that affect supplier selection, as this will give more in-depth insight regarding which factors are applicable. It is valuable because understanding what factors companies use to select suppliers will allow for appropriate interventions to be established in such a way that South African companies are selected as suppliers in global value chains.

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It was therefore decided to look at what Felix T.S. Chan et al. (2008) considered to be important decision variables for supplier selection. Thus, the key factors derived from this analysis will assist the intervention planning by ensuring key factors are considered. It will also allow an assessment of whether or not these industries are realistically supportable in South Africa. The analysis, shown in Figure B.1, followed by Chan *et al.* (2008) has four levels being goal, criteria, sub-criteria and decision alternatives at first, second, third and fourth levels respectively. Felix T.S. Chan et al. (2008) chose five prime criteria for their paper, with nineteen sub-criteria as shown in Figure B.1 below. The criteria and sub-criteria will be discussed in detail below.

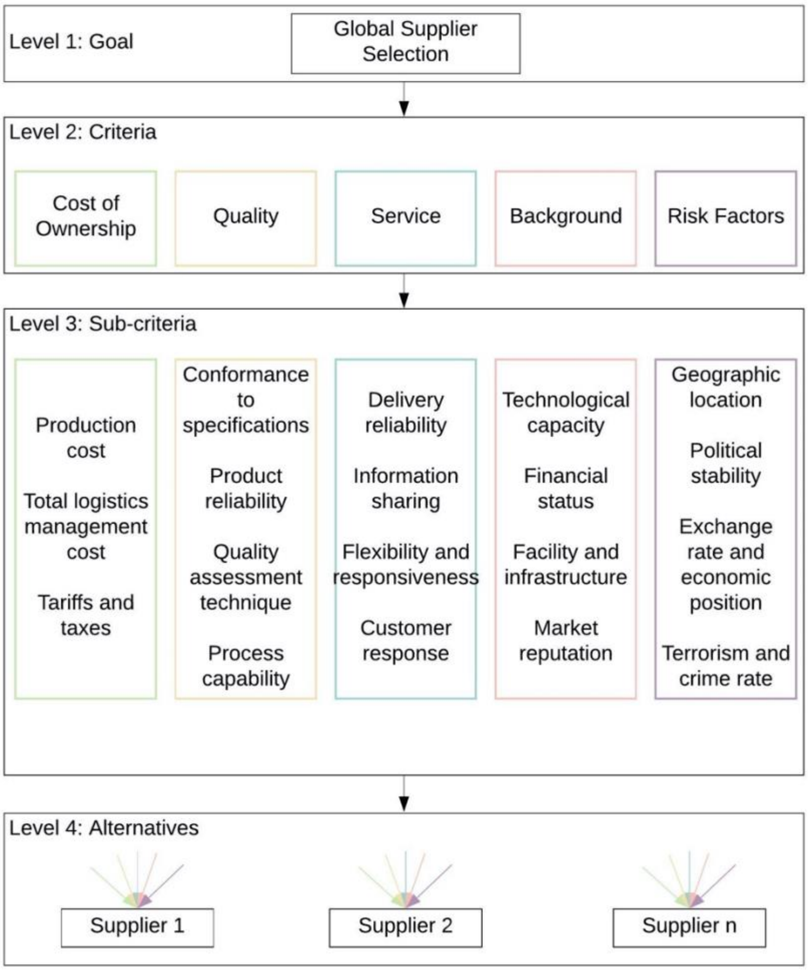

Figure B.1: Supplier selection analysis as described by Chan et al. (2008) (Publisher allows for re-use of figures in a thesis)

Total cost of ownership – if an organisation can reduce the cost of the operations, the organisation's profits will almost certainly increase. Organisations are looking for ways to lower supply base costs

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through lower purchase prices, import duties, documentation, transportation and communication costs. The sub-criteria for cost of ownership are:

- Production cost is a direct performance measurement; products that cost less are more attractive for customers. Suppliers with low manufacturing costs such as processing, maintenance, warranty and other manufacturing-related costs are ranked higher;
- Total logistics management cost includes the lengthy distribution channels, transport expenses, inventory cost, handling and packaging cost, damages and insurance. These costs increase drastically for international suppliers. Firms should also be aware that freight terms and conditions differ between countries; and
- Tariff and taxes are always a trade-off as foreign governments want to attract buyers and importing countries want to protect their local industry by imposing high tariffs. Firms should analyse these carefully, giving preference to countries with lower duties and taxes.

Quality of product – companies are leaning towards outsourcing, as more emphasis on quality can be placed at the source where the product is manufactured. The sub-criteria for analysing the quality of the product that a firm can produce are:

- Conformance to specification, that is the ability of the supplier to conform to the specifications of the manufacturers;
- Product reliability checks are to see whether the supplier can deliver reliable and durable products within the correct time period;
- Quality assessment techniques are to check whether the supplier is certified for strict quality assurance and has programmes in check to prevent quality failures; and
- Process capability checking, is whether suppliers have the actual capability to provide the promised quality goods.

Service performance – is checking whether a supplier can provide and maintain a required level of service to the manufacturer. These will promote the sustainability and length of the relationship between supplier, manufacturer and customer. The sub-criteria for service performance are discussed below:

- Delivery reliability is important, as there are firms with just-in-time principles that cannot afford any delays. Suppliers should allow manufactures to access exact delivery schedules;
- Information sharing – open sharing of information allows for better management, but there are some barriers such as language, business customs, ethical standards and electronic data compatibility that need to be assessed;

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- Flexibility and responsiveness – sometimes a firm needs to change according to customer demands, update price structures and order frequency, and the ability for suppliers to adapt to changes is important; and
- Customer response indicates customers' satisfaction towards certain suppliers, and therefore it is important to choose suppliers with good customer satisfaction.

Risk factor – effective analyses of supplier risks include the identification and monetisation of risk events, probability of occurrence and contingencies put in place by the firms. The following factors are good risk factors and the uncertainty lens can be used in supplier selection:

- Geographical location includes looking at the mother country, location of plant, nature of calamities and other similar factors;
- Political stability and foreign politics must be analysed, as this will affect business policies and will differ from country to country. Political unrest will also affect a supplier's ability to keep up with the demand schedule;
- Exchange rates and economic position can affect the local price control, inflation and currency exchange rates and need to be analysed thoroughly, as these can result in high hidden costs for international suppliers; and
- Terrorism and crime rates are also factors to consider, as these can hamper delivery performance that negatively affects customer satisfaction. Lower crime rates and less terrorism are more ideal locations.

From the selection criteria discussed above, it can be deduced, depending on the supplier, that each of the factors will have a different performance level attainable, and the supplier with the best overall performance is chosen. The factors discussed in level 2 under the criteria label establish the focal area for the relevant sub-criteria. Thus, if cost is important, the sub-criteria should be of importance and rated high; if quality is important its associated criteria are rated high. Therefore, there is a need to determine what the market values more (i.e. the market demand) so that each criterion playing a different importance can be assessed whether it is attainable by certain suppliers (i.e. the location) and the supplier with the best support of those factors wins. Although not all these factors are important, they still provide a good baseline of what should be considered when assessing how the potential factors related to the location can affect those factors.

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B.4. Overview of factors considered in location and supplier selection

Outsourcing plays a strategically important role within the business environment as recognised by managers and scholars in relevant studies (Quinn and Hilmer, 1994; Quinn, 1999; Nellore and Söderquist, 2000; Baldwin, Irani and Love, 2001). Due to economic globalisation and global networks between organisations, there has been a steady increase in offshoring activities (Dou and Sarkis, 2010). According to the OECD (2007) offshoring alternatives include offshoring to newly constructed plants or companies (e.g. foreign direct investment, offshoring to existing locations or to a sub-contractor not associated with the firm). Offshoring literature can be divided into two groups of thought with the first group focusing on the firms' choices of organisational structure (McLaren, 2000; Grossman and Helpman, 2002, 2004, 2005; Antrà and Helpman, 2004). The first group is at macroeconomic level and centres in the organisation's choices between outsourcing and integration as well as locational choices between domestic or foreign locations. In essence this group establishes whether the firm will be offshoring or not depending on their preferences. The more relevant group of literature for this research is the second group. This is because the second group of models is at firm level and focuses primarily on outsourcer evaluation and selection (Araz, Mizrak Ozfirat and Ozkarahan, 2007; Cao and Wang, 2007; Teixeira de Almeida, 2007). Understanding the key evaluation aspects that outsourcers are evaluated against allows the research to narrow down the search in understanding why some countries can be seen as more favourable to support an industry than other countries. The main drawback of the second group is that the location of economic activity determinants is not typically taken into account. The location of economic activities has been an important topic for economic analysis since the seminal work of Alfred Weber (impact of transport cost of the location decision), Johan Heinrich von Thünen (land-based model), Walter Christaller (central-place theory) and William Alonso (central-business district) (Arauzo Carod, 2005).

B.4.1. Strategic outsourcing and location assessment

Most international manufacturing organisations steadily shift their focus towards strategic outsourcing and sub-contractor selection as they grow, including evaluating factors such as cost, quality, flexibility and delivery of each alternative. All of them are valuable factors that should be considered during the intervention planning analysis. Among other potential methods, one method for South Africa to grow its economy is by making itself more attractive in the eyes of investors and businesses looking for strategic outsourcing options or local investors wanting to become suppliers. This method can be achieved through understanding what the various factors are that affect the

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decisions of facility locations, supplier selection and the addition of sustainability becoming increasingly important as well (Dou and Sarkis, 2010). Thus, South Africa can align its policies in such a way that companies looking at offshoring, outsourcing or supplier selection will consider South Africa as a strategically fit option.

Traditionally these factors were not given much prominence or importance until the work of Brown (2008) placed more emphasis on them. Thus, it is important to evaluate how these key factors drive the location decision for particular activities within an industry. This will give better insight to policymakers into attracting more foreign direct investments. Although each of these factors plays an important role, there is still the need to have a more holistic view and to include more metrics such as facility location and sustainability that encompass environmental and social aspects as well. In a paper written by Dou & Sarkis (2010) they explain how they developed a strategic decision model that incorporates sustainability factors whilst simultaneously considering facility location factors and supplier selection factors, discussed later on in this section. Dou & Sarkis (2010) set out a comprehensive set of factors that can be utilised for offshoring and outsourcing decision-making, giving a good indication of what factors affect the choice of location of economic activity.

In Table B.4 and Table B.5 are additional important location and supplier selection factors as identified by Dou and Sarkis (2010) that show the different factors that are also considered by management.

Table B.4: Strategic supplier selection factors

Strategic performance measures	
Cost	Low initial cost
	Compliance with cost analysis systems
	Cost reduction activities
	Compliance with sectorial prices
Quality	Conformance to quality
	Consistent with delivery schedule
	High regard to quality products
	Prompt communication responses
Time	Delivery speed
	Product development time
	Partnership formulation time
Flexibility	Response to changes in demand schedule
	Short set-up time
	Conflict resolution
	Service capability

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Innovativeness	New launch of products
	New use of technologies
Organisational factors	
Culture	Management attitude
	Strategic fit
	Top management compatibility
	Compatibility amongst different functional levels within company
	Supplier organisational structure.
Technology	Technology compatibility
	Assessment of future manufacturing capabilities
	Supplier speed in development
	Supplier design capability
	Technical capability
	Current manufacturing facilities and capabilities
Relationships	Long-term relationships
	Communication openness
	Reputation for integrity

Source: Dou & Sarkis (2010) *based the tables on the work* Sarkis & Talluri (2002, table 1)*; and* Chan (2003)

International facility location decisions have attracted more attention in recent years and have also become more important (Mudambi, 1995; Brush, Marutan and Karnani, 1999; Prasad, Babbar and Calis, 2000). Three different approaches have been used to explain facility location decisions namely: neoclassical, behavioural and institutional (Hayter, 1997). Neo-classical mainly focuses on cost minimisation and profit maximisation where factors such as labour cost, transportation cost, market size and locational business climate are of central importance. The problem with this approach is that it assumes perfect information is provided to the decision-makers. Behavioural approaches consider firms as agents with bounded rationality and imperfect information. Yet, they are still criticised for having assumed a very static nature that it is interacting within (Brouwer, Mariotti and van Ommeren, 2004). Institutional approaches include factors that formulate strategies and emphasis is placed on strategic issues such as competition, current facilities and market penetration (Hayter 1997).

Table B.5: Locational factors in facility location decision

Locational factors	
Strategic issues	Competition
	Current facilities
	Market size and penetration
	Expansion capabilities
Accessibility factors	Accessibility of suppliers
	Accessibility of customers

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	Accessibility of transportation services
	Proximity to production/ raw-material sources
	Proximity to markets and cities
Community factors	Physical attractiveness
	Attitude towards industry
	Police protection
Business climate factors	Suitability of repair and maintenance
	Legal services
	Supporting network
Labour factors	Labour costs
	Availability of semi/unskilled labour
	Availability of skilled labour
	Education system
	Training support
Utility services	Electrical services
	Cost of water supply
Risk factors	Foreign-exchange rate
	Government intervention
	Political risk
	Economic risk
	Legal risk
	Natural disaster risk
Plant site factors	Site development and construction costs
	Room for expansions
	Plant site adequacy and costs

Source: compiled from Hayter (1997 p107), Watts (198,7 p170 (adapted from Moriarty 1983, pp. 70-71)), Sarkis and Sundarraj (2002, Table 1)

These tables provide a holistic overview of the factors that organisations consider when looking at locations and suppliers. Thus intervention planning should account for these factors, allowing South African organisations to be the top performers when comparing performance related to these factors to industry leaders' performance. Although all these factors cover a wide spectrum of issues that need to be considered, their importance will vary from industry to industry as well as from country to country. Thus, a more location-specific analysis with regard to factors affecting the economic activity for industries is required. The key factors will remain the same, but the application of analysis will vary.

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B.4.2. Sustainability, environmental and social factors

Table B.6: Environmental metrics in supplier selection decisions

Categories	Factors	Sub-factors
Environmental Practices	Pollution Control	Remediation, end-of-pipe controls
	Pollution prevention	Product adaptation, Process adaptation
	Environmental management systems	Establishment of environment commitment and protection, Identification of environmental aspects, Planning of environmental objectives, Assign environmental responsibility, Checking and evaluation of environmental activities
Environmental Performance	Resource consumption	Consumption of energy, Consumption of raw materials, Consumption of water
	Pollution production	Production of polluting agents, Production of toxic products, Production of waste

Source: the tables are taken from the work done by authors, Dou & Sarkis (2010) *adapted the tables from* Klassen & Whybark (1999, p 606) *and* Gauthier (2005, p. 200)

Table B.7: Social metrics in supplier selection decisions

Social metrics in supplier selection decisions		
Categories	Factors	Sub-factors
Internal Social criteria	Employment practices	Disciplinary and security practices, Employee contracts, Equity labour sources. Diversity, Discrimination, Flexible working arrangements, Job opportunities, Employment compensation, Research and development, Career development
	Health and safety	Health and safety incidents, Health and safety practices
External social criteria	Local communities' influence	Health, Education, Housing, Service infrastructure, Mobility infrastructure, Regulatory and public services, supporting educational institutions, Sensory stimuli, Security, Cultural properties, Economic welfare and growth, Social cohesion, Social pathologies, Grants and donations, Supporting community projects
	Contractual stakeholder influence	Procurement standards, Partnership screens and standards, Consumers education
	Other stakeholder influence	Decision influence potential, Stakeholder empowerment, Collective audience, Selected audience, Stakeholder engagement

Source: the authors Dou & Sarkis (2010) *compiled the table from* (Gauthier, 2005; Labuschagne, Brent and Claasen, 2005; Presley, Meade and Sarkis, 2007).

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Table B.8: Environmental factors and sub-factors in facility location decisions

Factors	Sub-factors
Environmental health	Environmental burden of disease, Adequate sanitation, Drinking water, Indoor-air pollution, Urban particulates, Local ozone
Ecosystem vitality	Regional ozone, Sulphur dioxide emissions, Water quality, Water stress, Conservation risk, Effective conservation, Critical habitat protection, Marine-protected areas, Growing stock of forestry, Marine trophic, Trawling intensity of fishery irrigation stress Agricultural subsidies, Intensive cropland, Burned-land area of agriculture, Pesticide regulation, Greenhouse gas emission/capita, Greenhouse gas emissions/electricity generated, Industrial carbon intensity
Consumption and production matters	Materials use, Energy use, Depletion of non-renewable resources, Regeneration of renewable resources, Green consumption, Waste generation, Waste treatment, Waste disposal, Waste recycling

Source: the authors Dou & Sarkis (2010) *compiled the table from* (United Nations, 2001) *check sources*

Table B.9: Social factors and sub-factors in facility location decisions

Social factors and sub-factors in facility location decisions	
Factors	Sub-factors
Poverty	Income poverty, Income inequality, Sanitation, Drinking water, Access to energy, Living conditions
Governance	Corruption, Crime
Health	Life expectation at birth, Health care delivery, Nutritional status, Health status and risks, Old age provisions
Education	Educational level, Literacy.
Demographics	Population growth, Tourism.
Natural hazards	Vulnerability to natural hazards, Disaster preparedness and response
Individual development	Civil liberties and human rights, Equity, Individual autonomy and self-determination, Right to work, Social integration and participation, Gender and class-specific role, Material standard of living. Qualification, Specialisation, Family and life-planning horizon, Leisure and recreation, Arts
Community development	Security sense, Cultural properties, Social cohesion, Social pathologies

Source: the authors Dou & Sarkis (2010) *compiled the table from* (United Nations, 2001) *the revised CSD (the Commission on Sustainable Development)* (Brossel, 1999)

B.4.3. Supply chain considerations with location decisions

According to Altay and Ramirez (2010) supply chain risk management remains a managerial challenge that affects the performance of organisations, especially when aspects such as geographic dispersion and tighter collaborations open firms up to greater vulnerabilities. (Bode et al., 2011).

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Thus, Brusset (2016) looked at supply chain resilience and among a number of hypotheses established, two specifically focused on integration capabilities and flexibility capabilities. Integration capabilities referring to the extent to which manufacturers strategically collaborate with the partners in the supply chain to allow for efficient and effective delivery of products to the customers. Flexibility refers to the ease of responding to the change in demand requirements from the end-customers. Thus, South Africa should ensure attempting to allow manufacturers to effectively support integration and flexibility capabilities and their related factors.

Another study by Ellram, Tate and Petersen (2013) proposed three theoretical propositions to advance the understanding of manufacturing location decisions from an internalisation perspective. The first proposition argues that factors affecting a specific region's attractiveness for manufacturing changes over time, with government trade policies increasingly considered as a differentiator. The second proposition states that supply chain related factors are becoming more important in manufacturing location decisions. The third proposition argues that companies are moving beyond cost-saving to consider impact on total costs, profitability and customer value creation when determining preferred regions for manufacturing locations. The three propositions indicate that a multitude of factors will have an impact on the location decisions and depending on their importance, each will impact on the achievable success of manufacturers in certain locations differently.

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Appendix C

Location of economic activity

Table C.1: Factors that moderate importance of location determinants related to type of activity and firm (Bam, De Bruyne and Schutte, 2020)

Moderating factor	Illustrative impact
Industry-related	
Complexity of production processes	Complexity determines skills and experience required
Dynamism of the product market environment	Importance of knowledgeable supporting firms
Spillover importance of knowledge employed	Knowledge not easily spilled over beyond cluster
Economies of scale	Cost factors play a bigger role as production takes place in fewer places and differences are marginalised
Maturity of products	Mature products with established technologies are less dependent on science and more focused on manufacturing costs
Testability of product	Confidence in the management of quality control processes becomes very important
Firm-related	
Existing global footprint	Consider existing sites reducing impact of other location determinants
Experience in different regions	Experience in a region improves effective location decisions for firm in region due to experience
Interdependence between different firms' functions	Higher interdependence leads to other firms' locations becoming more important whilst reducing location determinants' importance to specific activity
Life cycle stages of company	Emerging firms have different priorities than existing firms
Size of firm	Smaller firms have less leverage over suppliers; thus, location of suppliers becomes important
Technology intensiveness	More skills will be required for more technology intensive jobs

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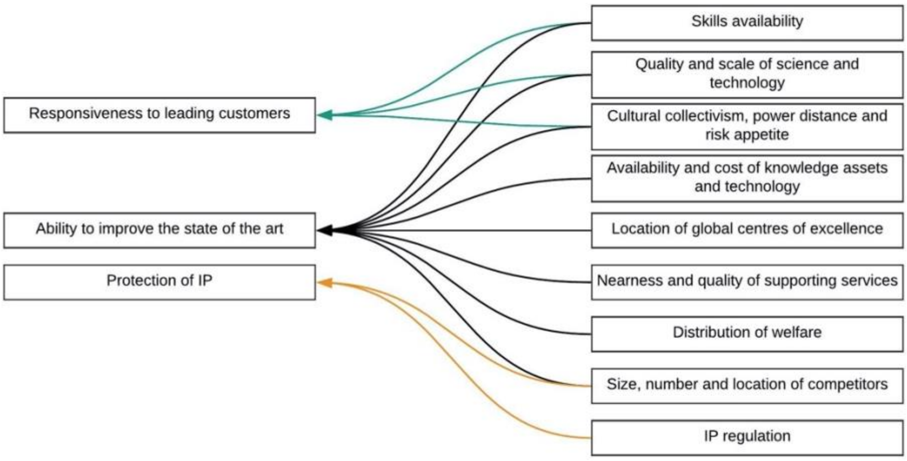

Figure C.1: Key location determinants that influence research-related performance (Bam, De Bruyne and Schutte, 2020)

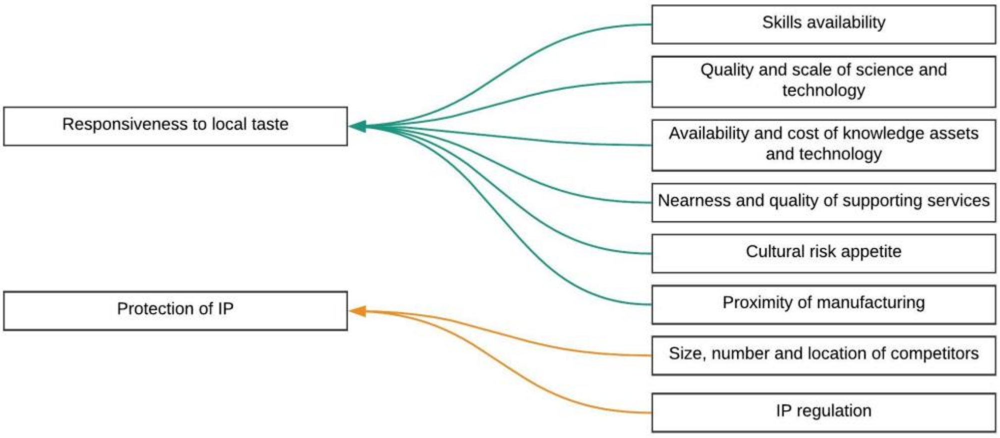

Figure C.2: Key location determinants that influence development-related performance (Bam, De Bruyne and Schutte, 2020)

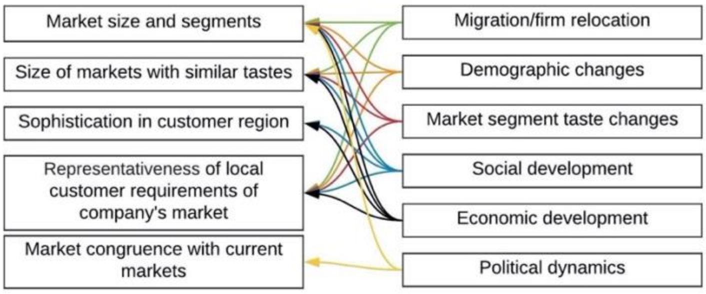

Figure C.3: Market-related dynamic

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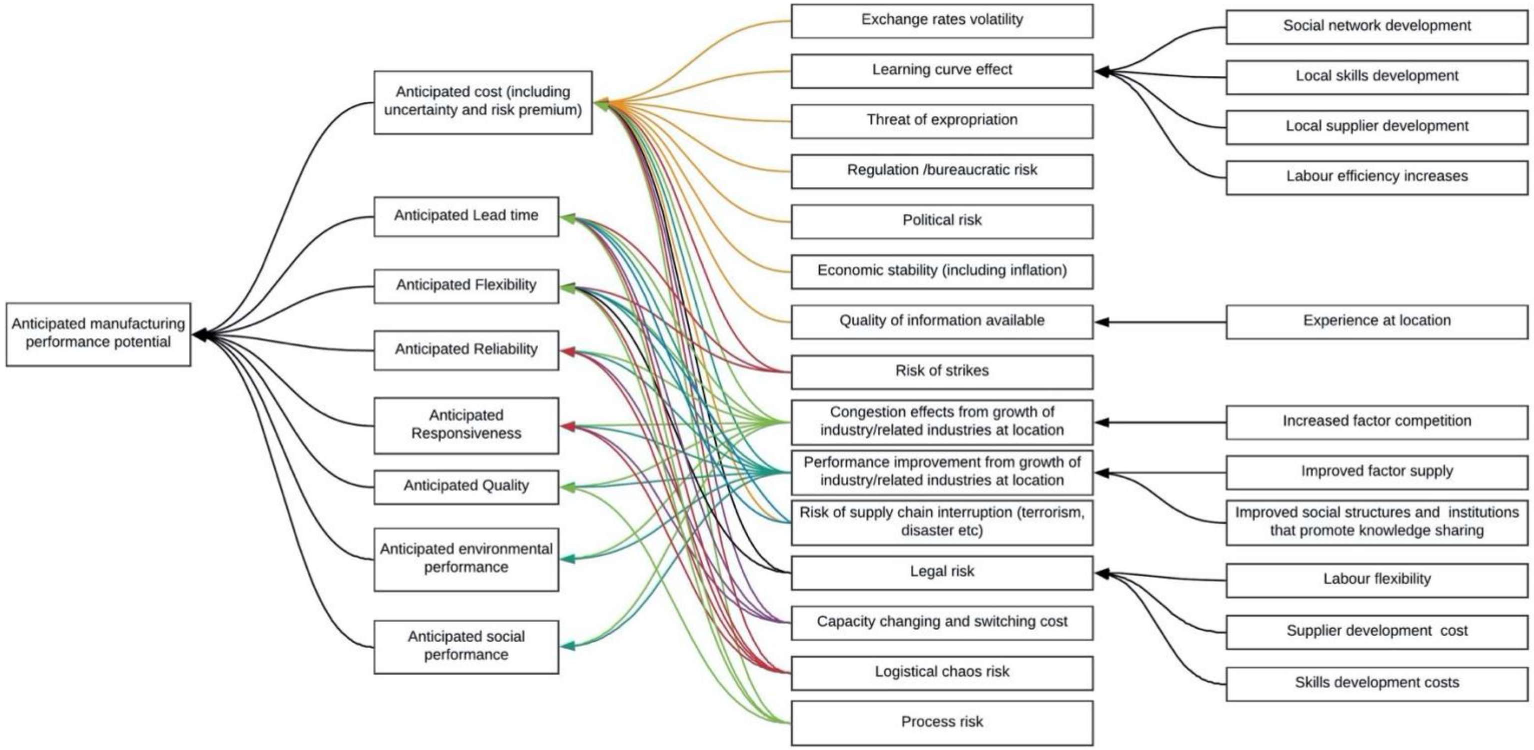

Figure C.4: Location-related dynamics - anticipated manufacturing performance (Bam, De Bruyne and Schutte, 2020)

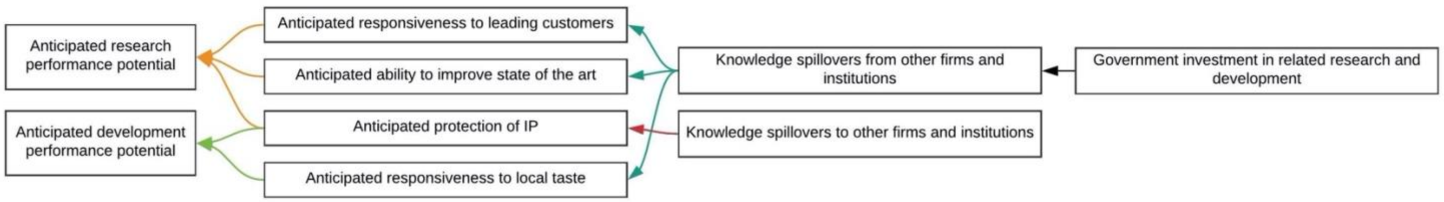

Figure C.5: Location-related dynamics anticipated research and development performance potential (Bam, De Bruyne and Schutte, 2020)

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Appendix D

HS Product category, description, trade code and CSV code

Table D.1: HS Product Category

Product Category	Category Description	Code	Description	CSV Code
Tier 1: Feedstock				
1	Waste and Scrap	810830	Titanium; waste and scrap	1,1,810830
2	Titanium Ores	261400	Titanium ores and concentrates	1,2,261400
3	Titanium Oxides	282300	Titanium oxides	1,3,282300
Tier 2: Primary Products				
4a	Unwrought Titanium	810820	Titanium; unwrought, powders	2,4,810820
4b	Other Titanium Forms	810890	Titanium; other than unwrought, n.e.c. in heading no. 8108	2,4,810890
5	Low-Pigment Content	320619	Colouring matter; pigments and preparations based on titanium dioxide, containing less than 80% by weight of titanium dioxide calculated on the dry weight	2,5,320619
6	High Pigment	320611	Colouring matter; pigments and preparations based on titanium dioxide, containing 80% or more by weight of titanium dioxide calculated on the dry matter	2,6,320611
Tier 3: Base Products				
7	Titanium Metal Alloys	720291	Ferro-alloys; ferro-titanium and ferro-silico-titanium	3,7,720291
Tier 4: Final Products				
8	Dyes	320415	Dyes; vat dyes (including those usable in that state as pigments) and preparations based thereon	4,8,320415

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		320417	Dyes; pigments and preparations based thereon	4,8,320417
9	Paints And Varnishes	320810	Paints and varnishes; based on polyesters, dispersed or dissolved in a non-aqueous medium	4,9,320810
		320820	Paints and varnishes; based on acrylic or vinyl polymers, dispersed or dissolved in a non-aqueous medium	4,9,320820
		320890	Paints and varnishes; based on polymers n.e.c. in heading no. 3208, dispersed or dissolved in a non-aqueous medium	4,9,320890
		320910	Paints and varnishes; based on acrylic or vinyl polymers, dispersed or dissolved in an aqueous medium	4,9,320910
		320990	Paints and varnishes; (based on polymers other than acrylic or vinyl), dispersed or dissolved in an aqueous medium	4,9,320990
10	Pigments - Paint Manufacturing	321210	Pigments; of a kind used in the manufacturing of paints, stamping foils	4,10,321210
		321290	Pigments; of a kind used in the manufacturing of paints, other than stamping foils	4,10,321290
11	Colour sets Artists	321310	Colours; in sets, of a kind used by artists, students or signboard painters	4,11,321310
		321390	Colours; (other than in sets), of a kind used by artists, students or signboard painters	4,11,321390
12	Ink	321511	Ink; for printing, black, whether or not concentrated or solid	4,12,321511
		321519	Ink; for printing, other than black, whether or not concentrated or solid	4,12,321519
		321590	Ink; writing, drawing and other inks, n.e.c. in heading no. 3215, whether or not concentrated or solid	4,12,321590
13	Cosmetic and toilet	330410	Cosmetic and toilet preparations; lip make-up	4,13,330410
		330420	Cosmetic and toilet preparations; eye make-up	4,13,330420
		330430	Cosmetic and toilet preparations; manicure or pedicure preparations	4,13,330430
		330491	Cosmetic and toilet preparations; powders, whether or not compressed (excluding lip, eye, manicure or pedicure preparations)	4,13,330491
		330499	Cosmetic and toilet preparations; n.e.c. in heading no. 3304, for the care of the skin (excluding medicaments, including sunscreen or suntan preparations)	4,13,330499

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14	Oral or dental	330610	Oral or dental hygiene preparations; dentifrices	4,14,330610
15	Plastic Tubes	391721	Plastics; tubes, pipes and hoses thereof, rigid, of polymers of ethylene	4,15,391721
		391722	Plastics; tubes, pipes and hoses thereof, rigid, of polymers of propylene	4,15,391722
		391723	Plastics; tubes, pipes and hoses thereof, rigid, of polymers of vinyl chloride	4,15,391723
		391729	Plastics; tubes, pipes and hoses thereof, rigid, of plastics n.e.c. in heading no. 3917	4,15,391729
16	Plastic plates	392111	Plastics; plates, sheets, film, foil and strip, of polymers of styrene, cellular	4,16,392111
		392112	Plastics; plates, sheets, film, foil and strip, of polymers of vinyl chloride, cellular	4,16,392112
		392113	Plastics; plates, sheets, film, foil and strip, of polyurethanes, cellular	4,16,392113
		392114	Plastics; plates, sheets, film, foil and strip, of regenerated cellulose, cellular	4,16,392114
		392119	Plastics; plates, sheets, film, foil and strip, of plastics n.e.c. in heading no. 3921, cellular	4,16,392119
		392190	Plastics; plates, sheets, film, foil and strip, other than cellular	4,16,392190
17	Plastic Household	392210	Plastics; baths, shower-baths, sinks and wash-basins	4,17,392210
		392220	Plastics; lavatory seats and covers	4,17,392220
		392410	Plastics; tableware and kitchenware	4,17,392410
		392490	Plastics; household articles and hygienic or toilet articles	4,17,392490
		392290	Plastics; bidets, lavatory pans, flushing cisterns and similar sanitary ware n.e.c. in heading no. 3922	4,17,392290
18	Plastic packing goods	392310	Plastics; boxes, cases, crates and similar articles for the conveyance or packing of goods	4,18,392310
		392329	Plastics; sacks and bags (including cones), for the conveyance or packing of goods, of plastics other than ethylene polymers	4,18,392329
		392330	Plastics; carboys, bottles, flasks and similar articles, for the conveyance or packing of goods	4,18,392330
		392340	Plastics; spools, cops, bobbins and similar supports, for the conveyance or packing of goods	4,18,392340

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		392350	Plastics; stoppers, lids, caps and other closures, for the conveyance or packing of goods	4,18,392350
		392390	Plastics; articles for the conveyance or packing of goods n.e.c. in heading no. 3923	4,18,392390
19	Plastic Builders	392510	Plastics; builders' ware, reservoirs, tanks, vats and similar containers of a capacity exceeding 300 litres	4,19,392510
		392520	Plastics; builders' ware, doors, windows and their frames and thresholds for doors	4,19,392520
		392530	Plastics; builders' ware, shutters, blinds (including venetian blinds) and similar articles and parts thereof	4,19,392530
		392590	Plastics; builders' ware, n.e.c. or included in heading no. 3925	4,19,392590
20	Plastic Office	392610	Plastics; office or school supplies	4,20,392610
		392630	Plastics; fittings for furniture, coachwork or the like	4,20,392630
21	Paper and Paperboard	470710	Paper or paperboard; waste and scrap, of unbleached Kraft paper or paperboard or corrugated paper or paperboard	4,21,470710
		470720	Paper or paperboard; waste and scrap, paper or paperboard made mainly of bleached chemical pulp, not coloured in the mass	4,21,470720
		470730	Paper or paperboard; waste and scrap, paper or paperboard made mainly of mechanical pulp (e.g. newspapers, journals and similar printed matter)	4,21,470730
		470790	Paper or paperboard; waste and scrap, of paper or paperboard n.e.c. in heading no. 4707 and of unsorted waste and scrap	4,21,470790
22	Newsprint	480100	Newsprint; made of fibres by a chemi-mechanical process or of a weight, per m2, of more than 57g but not more than 65g, in rolls or sheets	4,22,480100
23	Uncoated Paper	480220	Uncoated paper and paperboard (not 4801 or 4803); of a kind used as a base for photo-sensitive, heat-sensitive or electro-sensitive paper or paperboard, in rolls or sheets	4,23,480220
		480240	Uncoated paper and paperboard (not 4801 or 4803); wallpaper base, in rolls or sheets	4,23,480240

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		480254	Uncoated paper and paperboard (not 4801 or 4803); printing, writing or graphic, 10% or less by weight of mechanical or chemi-mechanical processed fibre, weighing less than 40g/m2, in rolls or sheets	4,23,480254
		480255	Uncoated paper and paperboard (not 4801 or 4803); printing, writing or graphic, 10% or less by weight of mechanical or chemi-mechanical processed fibre, weighing 40g/m2 to 150g/m2, in rolls	4,23,480255
		480256	Uncoated paper and paperboard (not 4801 or 4803); printing, writing or graphic, 10% or less by weight of mechanical or chemi-mechanical processed fibre, weight 40-150g/m2, in sheets 435mm or less by 297mm or less (unfolded)	4,23,480256
		480257	Uncoated paper and paperboard (not 4801 or 4803); printing, writing or graphic, 10% or less by weight of mechanical or chemi-mechanical processed fibre, weight 40-150g/m2, n.e.c. in item no. 4802.55 or 4802.56	4,23,480257
		480258	Uncoated paper and paperboard (not 4801 or 4803); printing, writing or graphic, 10% or less by weight of mechanical or chemi-mechanical processed fibre, weighing more than 150g/m2, rolls over 15cm wide or sheets one side over 36cm, other side over 15cm	4,23,480258
		480261	Uncoated paper and paperboard (not 4801 or 4803); over 10% by weight of mechanical or chemi-mechanical processed fibre, in rolls	4,23,480261
		480262	Uncoated paper and paperboard (not 4801 or 4803); over 10% by weight of mechanical or chemi-mechanical processed fibre, in sheets 435mm or less by 297mm or less (unfolded)	4,23,480262
		480269	Uncoated paper and paperboard (not 4801 or 4803); over 10% by weight of mechanical or chemi-mechanical processed fibre, other than rolls, other than sheets 435mm or less by 297mm or less (unfolded)	4,23,480269
24	Kraft Paper	480411	Kraft paper and paperboard; Kraftliner, uncoated, unbleached, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480411
		480421	Kraft paper and paperboard; sack Kraft paper, uncoated, unbleached, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480421

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		480431	Kraft paper and paperboard; uncoated, unbleached, weight 150g/m2 or less, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480431
		480441	Kraft paper and paperboard; uncoated, unbleached, weight more than 150g/m2, but less than 225g/m2, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480441
		480451	Kraft paper and paperboard; uncoated, unbleached, weight 225g/m2 or more, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480451
		480419	Kraft paper and paperboard; Kraftliner, uncoated, bleached, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480419
		480429	Kraft paper and paperboard; sack Kraft paper, uncoated, bleached, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480429
		480439	Kraft paper and paperboard; uncoated, bleached, weight 150g/m2 or less, in rolls or sheets, other than that of heading no. 4802 or 4803	4,24,480439
		480442	Kraft paper and paperboard; uncoated, weight between 150 and 225g/m2, bleached uniformly throughout, more than 95% of total fibre content consists of chemically processed wood fibres, in rolls or sheets	4,24,480442
		480452	Kraft paper and paperboard; uncoated, weight 225g/m2 or more, bleached uniformly throughout, more than 95% of total fibre content consists of chemically processed wood fibres, in rolls or sheets	4,24,480452
		481031	Kraft paper and paperboard; uniformly bleached throughout, coated with inorganic substances, more than 95% of chemically processed wood fibres, weight 150g/m2 or less, for non-graphic purposes, in rolls or sheets	4,24,481031
		481032	Kraft paper and paperboard; uniformly bleached throughout, coated with inorganic substances, more than 95% of chemically processed wood fibres, weight more than 150g/m2, for non-graphic purposes, in rolls or sheets	4,24,481032
25	Paper and Paperboard	480511	Paper and paperboard; uncoated, semi-chemical fluting paper, rolls or sheets	4,25,480511
		480512	Paper and paperboard; uncoated, straw fluting paper, rolls or sheets	4,25,480512

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		480519	Paper and paperboard; uncoated, fluting paper other than semi-chemical or straw, rolls or sheets	4,25,480519
		480524	Paper & paperboard; uncoated, testliner (recycled linerboard), weight 150g/m2, or less, in rolls or sheets	4,25,480524
		480525	Paper & paperboard; uncoated, testliner (recycled linerboard), weight over 150g/m2, in rolls or sheets	4,25,480525
		480530	Paper and paperboard; sulphite wrapping paper, uncoated, in rolls or sheets	4,25,480530
		480540	Paper and paperboard; filter paper and paperboard, uncoated, in rolls or sheets	4,25,480540
		480550	Paper and paperboard; felt paper and paperboard, uncoated, in rolls or sheets	4,25,480550
		480591	Paper and paperboard; uncoated, weight 150g/m2 or less, in rolls or sheets, n.e.c. in heading no.4805	4,25,480591
		480592	Paper and paperboard; uncoated, weight more than 150g/m2, but less than 225 g/m2, in rolls or sheets, n.e.c. in heading no. 4805	4,25,480592
		480593	Paper and paperboard; uncoated, weight 225/m2 or more, in rolls or sheets, n.e.c. in heading no. 4805	4,25,480593
26	Coated Paper and Paperboard	480620	Paper; greaseproof papers, in rolls or sheets	4,26,480620
		481013	Paper and paperboard; coated with kaolin or other inorganic substances, for printing & writing, graphics, containing no, or not more than 10% by weight of total fibres obtained by mechanical or chemi-mechanical process, in rolls	4,26,481013
		481014	Paper and paperboard; coated with kaolin or other inorganic substances, for printing/writing/graphics, having 10% or less by weight of total fibres got by mechanical/chemi-mechanical process, sheets, sides 435mm or less by 297mm or less, unfolded,	4,26,481014
		481019	Paper and paperboard; coated with kaolin or other inorganic substances, for printing/writing/graphics, having 10% or less by weight of total fibres got	4,26,481019

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			by mechanical/chemi-mechanical process, sides exceeding 435mm and 297mm, unfolded, sheets	
		481022	Paper and paperboard; coated with kaolin or other inorganic substances only, having more than 10% of mechanical or chemi-mechanical processed fibres, for writing, printing or other graphic purposes, light-weight coated paper, in rolls or sheets	4,26,481022
		481029	Paper and paperboard; coated with kaolin or other inorganic substances only, having more than 10% of mechanically processed fibres, (excluding light-weight paper), for writing, printing or other graphic purposes, in rolls or sheets	4,26,481029
27	Printed matter (Laminated)	490300	Printed matter; children's picture, drawing or colouring books	4,27,490300
		490510	Globes; printed	4,27,490510
		490591	Maps and hydrographic or similar charts; printed in book form, including atlases, topographical plans and similar	4,27,490591
		490599	Maps and hydrographic or similar charts; (printed other than in book form), including wall maps, topographical plans and similar	4,27,490599
		490600	Plans and drawings; for architectural, engineering, industrial, commercial, topographical or similar, being originals drawn by hand; hand-written texts; photo- graphic reproductions; their carbon copies	4,27,490600
		491000	Calendars; printed, of any kind, including calendar blocks	4,27,491000
		491110	Printed matter; trade advertising material, commercial catalogues and the like	4,27,491110
		491191	Printed matter; pictures, designs and photographs, n.e.c. in item no. 4911.10	4,27,491191
		491199	Printed matter; n.e.c. in heading no. 4911	4,27,491199
28	Cutlery	821510	Cutlery; sets of assorted articles (e.g. spoons, forks, ladles, skimmers, cake-servers, fish-knives, butter-knives, sugar tongs and similar), with at least one article plated with precious metal	4,28,821510
29	Water Boilers	840211	Boilers; watertube boilers with a steam production exceeding 45t per hour	4,29,840211

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		840212	Boilers; watertube boilers with a steam production not exceeding 45t per hour	4,29,840212
		840219	Boilers; vapour-generating boilers, including hybrid boilers n.e.c. in heading no. 8402	4,29,840219
		840290	Boilers; parts of steam or other vapour-generating boilers	4,29,840290
		840220	Boilers; super-heated water boilers	4,29,840220
		840310	Boilers; central heating boilers (excluding those of heading no. 8402)	4,29,840310
		840390	Boilers; parts of central heating boilers (excluding those of heading no. 8402)	4,29,840390
		840420	Boilers; condensers, for steam or other vapour power units	4,29,840420
		840490	Boilers; parts of auxiliary plant, for use with boilers of heading no. 8402 and 8403 and parts of condensers for steam or other vapour power units	4,29,840490
30	Steam Turbines (Marine propulsion and other)	840610	Turbines; steam and other vapour turbines, for marine propulsion	4,30,840610
		840681	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output exceeding 40MW	4,30,840681
		840682	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output not exceeding 40MW	4,30,840682
		840690	Turbines; parts of steam and other vapour turbines	4,30,840690
31	Engines	840710	Engines; for aircraft, spark-ignition reciprocating or rotary internal combustion piston engines	4,31,840710
		840721	Engines; outboard motors for marine propulsion, spark-ignition reciprocating or rotary internal combustion piston engines	4,31,840721
		840729	Engines; for marine propulsion, (other than outboard motors), spark-ignition reciprocating or rotary internal combustion piston engines	4,31,840729
		840910	Engines; parts of aircraft engines (spark-ignition reciprocating or rotary internal combustion piston engines)	4,31,840910
		840991	Engines; parts, suitable for use solely or principally with spark-ignition internal combustion piston engines (for other than aircraft)	4,31,840991

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		840999	Engines; parts for internal combustion piston engines (excluding spark-ignition)	4,31,840999
32	Turbines Hydraulic	841011	Turbines; hydraulic turbines and water wheels, of a power not exceeding 1000kW	4,32,841011
		841012	Turbines; hydraulic turbines and water wheels, of a power exceeding 1000kW but not exceeding 10000kW	4,32,841012
		841013	Turbines; hydraulic turbines and water wheels, of a power exceeding 10000kW	4,32,841013
		841090	Turbines; parts of hydraulic turbines and water wheels, including regulators	4,32,841090
		841181	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power not exceeding 5000kW	4,32,841181
		841182	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power exceeding 5000kW	4,32,841182
		841191	Turbines; parts of turbo-jets and turbo-propellers	4,32,841191
		841199	Turbines; parts of gas turbines (excluding turbo-jets and turbo-propellers)	4,32,841199
33	Hydraulic systems	842541	Jacks; built-in jacking systems of a type used in garages, for raising vehicles	4,33,842541
		846789	Tools; for working in the hand, (other than chain saws), hydraulic or with self-contained non-electric motor, (not pneumatic)	4,33,846789
		903281	Regulating or controlling instruments and apparatus; automatic, hydraulic or pneumatic	4,33,903281
		842542	Jacks and hoists; hydraulic, of a kind used for raising vehicles	4,33,842542
		842549	Jacks and hoists; (other than hydraulic), of a kind used for raising vehicles	4,33,842549
34	Vehicle parts	870880	Vehicle parts; suspension systems and parts thereof (including shock-absorbers)	4,34,870880
		830230	Mountings, fittings and similar articles; for motor vehicles, of base metal	4,34,830230
		870892	Vehicle parts; silencers (mufflers) and exhaust pipes; parts thereof	4,34,870892
35	Tanks	871000	Tanks and other armoured fighting vehicles; motorised, whether or not fitted with weapons, and parts of such vehicles	4,35,871000

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36	Cycles	871491	Cycles; frames and forks, and parts thereof	4,36,871491
		871495	Cycles; parts thereof, saddles	4,36,871495
		871496	Cycles; parts, pedals and crank-gear, and parts thereof	4,36,871496
37	Helicopters	880211	Helicopters; of an unladen weight not exceeding 2000 *kg*	4,37,880211
		880212	Helicopters; of an unladen weight exceeding 2000 *kg*	4,37,880212
38	Aerospace and other aircrafts	880220	Aeroplanes and other aircraft; of an unladen weight not exceeding 2000 *kg*	4,38,880220
		880230	Aeroplanes and other aircraft; of an unladen weight exceeding 2000 *kg* but not exceeding 15 000 *kg*	4,38,880230
		880240	Aeroplanes and other aircraft; of an unladen weight exceeding 15 000*kg*	4,38,880240
39	Aircraft and Spacecraft	880260	Spacecraft;(including satellites) and suborbital and spacecraft vehicles	4,39,880260
		880310	Aircraft and spacecraft; propellers and rotors and parts thereof	4,39,880310
		880320	Aircraft and spacecraft; under-carriages and parts thereof	4,39,880320
		880330	Aircraft and spacecraft; parts of aeroplanes or helicopters n.e.c. in heading no. 8803	4,39,880330
		880390	Aircraft and spacecraft; parts thereof n.e.c. in chapter 88	4,39,880390
		880510	Aircraft launching gear, deck-arrestor or similar gear and parts thereof	4,39,880510
40	Frames and Mountings	900311	Frames and mountings; for spectacles, goggles or the like, of plastics	4,40,900311
		900319	Frames and mountings; for spectacles, goggles or the like, of materials other than plastics	4,40,900319
		900390	Frames and mountings; parts for spectacles, goggles or the like	4,41,900390
41	Instruments	902780	Instruments and apparatus; for physical or chemical analysis, for measuring or checking viscosity, porosity, expansion, surface tension or quantities of heat, sound or light, n.e.c. in heading no. 9027	4,41,902780
42	Firearms parts	930119	Military weapons; other than revolvers, pistols and arms of heading 9307; artillery weapons (for example, guns, howitzers and mortars), not self-propelled	4,42,930119
		930120	Military weapons; other than revolvers, pistols and arms of heading 9307; rocket launchers: flame-throwers; grenade launchers, torpedo tubes and similar projectors	4,42,930120

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		930190	Military weapons; other than revolvers, pistols and arms of heading 9307; other weapons not elsewhere included in heading 9301	4,42,930190
		930400	Firearms; (e.g. spring, air or gas guns and pistols, truncheons), excluding those of heading no. 9307	4,42,930400
		930510	Firearms; parts and accessories, of revolvers or pistols	4,42,930510
		930521	Firearms; parts and accessories, of shotgun barrels	4,42,930521
		930529	Firearms; parts and accessories, of shotguns or rifles of heading no. 9303, other than shotgun barrels	4,42,930529
		930591	Firearms; parts and accessories, of military weapons of heading 9301	4,42,930591
		930599	Firearms; parts and accessories, of firearms other than the military weapons of heading 9301	4,42,930599
43	Sport	950631	Golf clubs; complete	4,43,950631
		950710	Fishing rods	4,43,950710
44	Watch parts	910811	Watch movements; complete and assembled, electrically operated, with mechanical display only or with a device to which a mechanical display can be incorporated	4,44,910811
		910121	Wristwatches; (not electrically operated), automatic winding, whether or not incorporating a stop-watch facility, case of precious metal or of metal clad with precious metal	4,44,910121
45	Medical	902110	Orthopaedic or fracture appliances	4,45,902110
		902121	Dental fittings; artificial teeth	4,45,902121
		902129	Dental fittings; other than artificial teeth	4,45,902129
		902131	Artificial parts of the body	4,45,902131
		902139	Artificial parts of the body; excluding artificial joints	4,45,902139
46	Cranes	842620	Cranes; tower cranes	4,46,842620
		842641	Cranes; self-propelled derricks and cranes, on tyres, n.e.c. in heading no. 8426	4,46,842641
		842649	Cranes; self-propelled derricks and cranes, not on tyres, n.e.c. in heading no. 8426	4,46,842641

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Appendix E

SITC Product category

Table E.1: SITC Product Category

Product Category #	Product Category Description	SITC Trade Codes Assigned to Category
1	Waste and Scrap	6899
2	Titanium Ores	2879
3	Titanium Oxidated	5224; 5225
4	Unwrought Titanium]	6998
5	Low/High Content Pigment	5331
6	Titanium Alloys	6716
7	Paints and Varnishes	5311; 5332; 5334; 5335
8	Plastics	8959; 8939
9	Other Plastics	5839
10	Building Plastics	8932; 8931
11	Clothing Apparel	8482
12	Recovered Waste	2511
13	Newsprint	6411; 6415; 6413; 6417; 6412
14	Journals	8922; 8921; 8924; 8928
15	Steam Plants	7111; 7119; 7112
16	Boilers	8121
17	Steam Units	7126; 7129
18	Combustion Parts	7131; 7139
19	Gas Turbines	7148; 7149
20	Engines	7188
21	Pulley	7442
22	Parts	7929
23	Spectacles	8842
24	Armoured Vehicles	9510
25	Sport and Other	8946; 8947
26	Watches	8851

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Appendix F

MATLAB Code

```
function
[Densities,Distance,SARCAMat,ProductSum,M,MAbs,Countries,CountryCompInd,ProductCompI
nd,CP,Prox,Centrality,DistanceAndOpporGain,GVCFull,GVCAct,GVCTier,P2AllP,P2P,A2A,T2T,
PercInGVCProd,PercInGVCAct,PercInGVCTier,P2AllP_Vec,P2P_Vec,BaseLineMetrics,BaseRC
ASpace,GVCFullBaseRCA,DistReq3,Comp3,OpporGainScenarios3,BestFrom3Comp,BestFrom3O
ppor,GVCRCAScenarios1,GVCRCAScenarios2,GVCRCAScenarios3,ProxSums,Products,BestCo
mplexityContr,SumCompContr,NumberInActToBeAdded,tS1_Seconds,tS2_Seconds,tS3_Minutes]
= CaseStudyReworked(All2014Mat,All2014CA,SARaw)

MainTime = tic;

%Requires the loading into the Workspace the Raw World Data in Matrix Form and CA
%Form (already in alphabetical order) and the Raw Country Data in Matrix
%Form

%All2014Mat; % Format = ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6
Export RCA; 7 Import RCA)
%All2014CA; % Format = ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6 Export
RCA; 7 Import RCA)
%SARaw; % Format = ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6 Export
RCA; 7 Import RCA)

%% Declarations (Changeable inputs)
NumIters = 18;

%% UpFront calculations:
Products = unique(All2014Mat(:,3));

%% Tranform country data to create country RCA matrix and sum world production

%Outputs:
%SARCAMat  % Format = ( 1 hs92code; 2 Export of Country; 3 World Export of product; 4 SA
Good Percentage of world export of good; 5 % SA Good Percentage of SA exports; 6 Good
Percentage of world exports; 7 SA RCA)
%ProductSum % Format = 1 hs92 code; 2 World exports of product

[SARCAMat,ProductSum] = TransformCountry(All2014Mat,SARaw,Products);



%% Generate M matrixes

[M,MAbs,Countries] = generateM(Products,All2014Mat,All2014CA);

%% Calculate complexity
```

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```
%CountryCompInd 1) complexities)
%ProductCompInd 1) complexities
[CountryCompInd,ProductCompInd] = CalcComplexity(M,Products,Countries,NumIters);

%% Calculate conditional probability and proximity matrix

%This code generates:
%1)CP(i,j) -> the conditional probability matrix.
%      It indicates the probability of an RCA in j given an RCA in i.
%       Its size is CP(Products,Products)
%2)Prox(i,j) -> the matrix of product proximities
%3)Centrality(i,2) a Matrix of ProductCentrality per product (1)
%HsCode; 2) Centrality )

[CP,Prox,Centrality] = GenerateCPandProxMat(M,Products,Countries);

%% Calculate Opportunity Gain and Distance

%RCA   % Format = ( 1 hs92code; 2 SA RCA)

RCA = SARCAMat(:,[1 7]);

%DistanceAndOpporGain 1) HsCode; 2) Distance; 3) Distance if opportunity; 4) OpporGain; 5)
OpporGain if Opportunity 6) Density; 7) Density if Oppor
[DistanceAndOpporGain,Densities,Distance,ProxSums] =
DistanceAndGain(Prox,RCA,Products,ProductCompInd);

%% Calculate GVC values

GVCMapping = csvread('Code input.csv'); %GVCData 1) Tier#; 2) GVC Activity#; 3) HS Code

[GVCFull,GVCAct,GVCTier] =
GVCDistanceAndGain(DistanceAndOpporGain,ProductCompInd,GVCMapping,Products,SARCA
Mat,Densities);

dlmwrite('GVCTierResults.txt',GVCTier,'precision',10);
dlmwrite('GVCActResults.txt',GVCAct,'precision',10);
dlmwrite('GVCFullResults.txt',GVCFull,'precision',10);

[P2AllP,P2P,A2A,T2T,PercInGVCProd,PercInGVCAct,PercInGVCTier] =
CalcGVCProximities(GVCFull,GVCAct,GVCTier,Prox,Products);

dlmwrite('GVCProdToAllProductProx.txt',P2AllP,'precision',10);
dlmwrite('GVCProdToGVCProductProx.txt',P2AllP,'precision',10);
dlmwrite('GVCActToGVCActProx.txt',A2A,'precision',10);
dlmwrite('GVCTierToGVCTierProx.txt',T2T,'precision',10);

dlmwrite('AllProducts.txt',Products,'precision',10);
dlmwrite('GVCProducts.txt',GVCFull(:,3),'precision',10);
```

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```
%% Calculate GVC Proximities

P2AllP_Vec = reshape(P2AllP,[],1);
P2P_Vec = reshape(P2P,[],1);

%% Set baseline for dynamic model

%BaseLineMetrics = zeros(9,1); % 1) Opportunity Value; 2) Average complexity of products within the value chain with RCA > 1; 3) Avg distance to Products in the VC with RCA < 1; 4) Average complexity of products within the PS with RCA > 1; 5) Average distance to products in the product space with RCA <1; 6) Num in GVC; 7) Sum of complexity in GVC; 8) Num in PS; 9) Sum of complexity in PS

[BaseLineMetrics] = CalcBaselineMetrics(Prox,RCA,Products,ProductCompInd,ProxSums,GVCFull,DistanceAndOpporGain,SARCAMat);

dlmwrite('BaseLineMetrics.txt',BaseLineMetrics,'precision',10);

%% Calculate RCA Space For Base

BaseRCASpace = CalculateBaseRCASpace(RCA); %Normalise current Product space

[GVCFullBaseRCA] = CalculateGVCFullBase(GVCFull); %Normalise current GVC Full

NumProductsCurInGVC = BaseLineMetrics(6);
NumProductsCurInPS = BaseLineMetrics(8);

CurrentSumOfComplexityInGVC = BaseLineMetrics(7);
CurrentSumOfComplexityInPS = BaseLineMetrics(9);


%% Calculate Scenario RCA Space for 1

Scenario1 = tic;

[GVCRCAScenarioCont] = CalcGVCRCASpaceScenarioCont(GVCFull,GVCAct,Products); % Calculate raw contributions for each activity

[GVCFullRCAScenarioCont] = CalcGVCFullRCAScenarioCont(GVCFull,GVCAct); % Calculate raw contributions for each activity

[GVCRCAScenarios1] = CalcGVCRCASpaceScenarios1(GVCRCAScenarioCont,BaseRCASpace,GVCAct,Products); % Calculate Scenarios by adding baseline and Scenario contributions

[GVCFullRCAScenarios1] = CalcGVCFullRCAScenarios1(GVCFullRCAScenarioCont,GVCFullBaseRCA,GVCAct,GVCFull); % Calculate Scenarios by adding baseline and Scenario contributions


%% Calculate Metrics for RCA scenarios after 1
```

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```
[Comp1 SumCompContr NumberInActToBeAdded] =
CalcCompContr(GVCFull,GVCAct,NumProductsCurInGVC,CurrentSumOfComplexityInGVC); %
Calculate Complexity values for Different Activities based on the unexploited items

dlmwrite('SumCompContr.txt',SumCompContr,'precision',10);
dlmwrite('NumberInActToBeAdded.txt',NumberInActToBeAdded,'precision',10);


ComplexityCalcsFor1 = 'Complete'

[DistReq1] = CalcDist1(GVCFull,GVCAct); %Calculate the distance to different activities during
first iter

OpporValScenarios1 =
CalcOppValScenarios1(Products,Prox,ProductCompInd,GVCRCAScenarios1,GVCAct,BaseRCAS
pace,ProxSums); %Calculate OpporGain for different activities during first iter

OpporGainScenarios1 = OpporValScenarios1 - BaseLineMetrics(1);

Round1Metrics = [Comp1 OpporGainScenarios1 DistReq1];

dlmwrite('Round1Metrics.txt',Round1Metrics,'precision',10);

%% Calculate winners after 1
% 7.6 *3 = 22.8


ScenariosDistances = ones(36,1);

for i = 1:36

  ScenariosDistances(i) = 2*i-1;

end

[BestFrom1Comp BestFrom1Oppor BestComplexityContr BestOpporGain] =
CalcBestFrom1(Round1Metrics,ScenariosDistances,BaseLineMetrics);

dlmwrite('BestFrom1Comp.txt',BestFrom1Comp,'precision',10);
dlmwrite('BestFrom1Oppor.txt',BestFrom1Oppor,'precision',10);

CalculationsFor1Metrics = 'Complete'

tS1_Seconds = toc(Scenario1)


%% Calculate Scenario RCA Space for 2

Scenario2 = tic;
```

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```
[GVCRCAScenarios2] = CalcGVCRCASpaceScenarios2(GVCRCAScenarioCont,BaseRCASpace,GVCAct,Products); % Calculate Scenarios by adding baseline and Scenario contributions

[GVCFullRCAScenarios2] = CalcGVCFullRCAScenarios2(GVCFullRCAScenarioCont,GVCFullBaseRCA,GVCAct,GVCFull); % Calculate Scenarios by adding baseline and Scenario contributions

%% Calculate Metrics for RCA Scenarios after 2

[Comp2] = CalcCompContr2(GVCAct,NumProductsCurInGVC,CurrentSumOfComplexityInGVC,SumCompContr,NumberInActToBeAdded); % Calculate Complexity values for Different Activities based on the unexploited items

dlmwrite('CompContr2.txt',Comp2,'precision',10);

[DistReq2] = CalcDist2(GVCFull,GVCAct,GVCFullRCAScenarios1,GVCRCAScenarios1,ProxSums,DistReq1,Products,Prox); %Calculate the distance to different activities during first iter

dlmwrite('DistReq2.txt',DistReq2,'precision',10);
dlmwrite('DistReq1.txt',DistReq1,'precision',10);


OpporValScenarios2 = CalcOppValScenarios2(Products,Prox,ProductCompInd,GVCRCAScenarios2,GVCAct,BaseRCASpace,ProxSums); %Calculate OpporGain for different activities during first iter

OpporGainScenarios2 = OpporValScenarios2 - BaseLineMetrics(1);

%% Calculate winners after 2

[BestFrom2Comp BestFrom2Oppor BestComplexityContr BestOpporGain] = CalcBestFrom2(Comp2,DistReq2,OpporGainScenarios2,ScenariosDistances,BestFrom1Comp,BestFrom1Oppor,BestComplexityContr,BestOpporGain);

dlmwrite('BestFrom2Comp.txt',BestFrom2Comp,'precision',10);
dlmwrite('BestFrom2Oppor.txt',BestFrom2Oppor,'precision',10);

CalculationsFor2Metrics = 'Complete'

tS2_Seconds = toc(Scenario2)

%% Calculate Scenario RCA Space for 3

Scenario3 = tic;

[GVCRCAScenarios3] = CalcGVCRCASpaceScenarios3(GVCRCAScenarioCont,BaseRCASpace,GVCAct,Products); % Calculate Scenarios by adding baseline and Scenario contributions
```

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```
[GVCFullRCAScenarios3] = CalcGVCFullRCAScenarios3(GVCFullRCAScenarioCont,GVCFullBaseRCA,GVCAct,GVCFull); % Calculate Scenarios by adding baseline and Scenario contributions

%% Calculate Metrics for RCA Scenarios after 3

[Comp3] = CalcCompContr3(GVCAct,NumProductsCurInGVC,CurrentSumOfComplexityInGVC,SumCompContr,NumberInActToBeAdded); % Calculate Complexity values for Different Activities based on the unexploited items

dlmwrite('CompContr3.txt',Comp3(3,3,:),'precision',10);

[DistReq3] = CalcDist3(GVCFull,GVCAct,GVCFullRCAScenarios2,GVCRCAScenarios2,ProxSums,DistReq1,DistReq2,Products,Prox); %Calculate the distance to different activities during first iter

dlmwrite('DistReq3.txt',DistReq3(3,3,:),'precision',10);


OpporValScenarios3 = CalcOppValScenarios3(Products,Prox,ProductCompInd,GVCRCAScenarios3,GVCAct,BaseRCASpace,ProxSums); %Calculate OpporGain for different activities during first iter

OpporGainScenarios3 = OpporValScenarios3 - BaseLineMetrics(1);

CalculationsFor3Metrics = 'Complete'

%% Calculate winners after 3

[BestFrom3Comp BestFrom3Oppor BestComplexityContr BestOpporGain] = CalcBestFrom3(Comp3,DistReq3,OpporGainScenarios3,ScenariosDistances,BestFrom2Comp,BestFrom2Oppor,BestComplexityContr,BestOpporGain);

dlmwrite('BestFrom3Comp.txt',BestFrom3Comp,'precision',10);
dlmwrite('BestFrom3Oppor.txt',BestFrom3Oppor,'precision',10);

%% Calculate metrics of winners

[MetricsForWinnersComp MetricsForWinnersOppor] = CalcMetricsOfWinner(BestFrom3Comp,BestFrom3Oppor,GVCRCAScenarios3,GVCRCAScenarios2,GVCRCAScenarios1,Prox,ProxSums,Products,GVCFull);

dlmwrite('MetricsForWinnersComp.txt',MetricsForWinnersComp,'precision',10);
dlmwrite('MetricsForWinnersOppor.txt',MetricsForWinnersOppor,'precision',10);

tS3_Minutes = toc(Scenario3) / 60
tMain = toc(MainTime) / 60

end

function [SARCAMat,ProductSum] = TransformCountry(All2014Mat,CountryRaw,Products)
```

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```
%This macro transforms the raw data to calculate the country RCA
%It also Sums The world production for a specific good and calculates the
%RCA for the involved countries

% The resulting Arrays are as follows:
SARCAMat = zeros(size(Products,1),7); % Final format = ( 1 hs92code; 2 Export of Country; 3 World Export of product; 4 SA Good Percentage of world export of good; 5 % SA Good Percentage of SA exports; 6  Good Percentage of world exports; 7 SA RCA)
ProductSum = zeros(size(Products,1),2); %Final format = 1 hs92code; Sum of world production

%All2014Mat; % Format = ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6 Export RCA; 7 Import RCA)
%CountryRaw; % Format =  ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6 Export RCA; 7 Import RCA)

Progress = 'TransformCountry_Start'

SARCAMat(:,1) = Products;
ProductSum(:,1) = Products;


for i = 1:size(Products,1) % run through all HS92s

   for j = 1:size(CountryRaw,1) %Run through all Country Exports

      if  CountryRaw(j,3) == SARCAMat(i,1)

         SARCAMat(i,2) = SARCAMat(i,2) + CountryRaw(j,4); %Add country export to column 2

      end


   end


   for j = 1:size(All2014Mat,1) %Run through all raw world Exports entries

      if  All2014Mat(j,3) == ProductSum(i,1)

         ProductSum(i,2) = ProductSum(i,2) + All2014Mat(j,4); % Add up world production to column 2 of Product Sum Matrix

      end

   end

end

SARCAMat(:,3) = ProductSum(:,2);

TotalSA = sum(SARCAMat(:,2))
```

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```
TotalWorld = sum(ProductSum(:,2))

SARCAMat(:,4) = SARCAMat(:,2) ./ SARCAMat(:,3); % SA Good Percentage of world export of good
SARCAMat(:,5) = SARCAMat(:,2) ./ TotalSA;  % SA Good Percentage of SA exports
SARCAMat(:,6) = SARCAMat(:,3) ./ TotalWorld;  % Good Percentage of world exports
SARCAMat(:,7) = SARCAMat(:,5) ./ SARCAMat(:,6); %SA RCA

% xlswrite('ProductSum.xlsx',ProductSum)
% xlswrite('SARCA20146D.xlsx',CountryRCAMat)

Progress = 'TransformCountry_Finish'


end

function [M,MAbs,Countries] = generateM(Products,All2014Mat,All2014CA)

Progress = 'generateM_Start'

%This code generates the M and Mabs (with the actual RCA)

%IT requires the loading of:
%1) All2014CA; Format = % Format = ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6 Export RCA; 7 Import RCA) (It requires that the countries are in alphabetical Order)
%2) All2014Mat; % Format = ( 1 Year; 2 Country; 3 hs92code; 4 Export Value; 5 Import value: 6 Export RCA; 7 Import RCA) (It requires that the countries are in alphabetical Order)
%3) hs92codes;

CountriesDupl = All2014CA(:,2); %Reads all country names into array (Sorted that names of countries are in alphabetical order)

Countries = unique(CountriesDupl); %Removes duplicates

ProductRCA = All2014Mat(:,[3 6]); %Filter only necessary parts of All2014Mat (Sorted that names of countries are in alphabetical order)

MAbs = zeros(size(Countries,1),size(Products,1)); %Instantiate MAbs
M = zeros(size(Countries,1),size(Products,1)); %Instantiate M

c = 1; %country number

for k = 1:size(ProductRCA,1) %Run through all rows of All2014 array

   if k > 1
      if strcmp(CountriesDupl(k),CountriesDupl(k-1))
      else
         c=c+1;
      end
   end

      for j = 1:size(Products,1) %Run through the M array columns
```

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```
            if Products(j) == ProductRCA(k,1)

                MAbs(c,j) = ProductRCA(k,2);

                if MAbs(c,j) > 1

                    M(c,j) = 1;

                end

            end

        end

end

Progress = 'generateM_Finish'

end

function [CountryCompInd,ProductCompInd] = CalcComplexity(M,Products,Countries,NumIters)

Progress = 'CalcComplexity_Start'

%This code generates the complexity of countries and products

%Output:
%CountryComplexityIndex6D(countries,complexities)
%ProductComplexityIndex6D(Products,complexities)
%Countries
%Products6D

%To Run the code it requires:
%1) M2D matrix (with 1's and 0's)
%2) Products2D
%3) Countries

M = M;

Kc0 = zeros(size(Countries,1),1); %Indicates the number of products each country produces (array
of diversity)

for i = 1:size(Countries,1)

    Kc0(i) = sum(M(i,:)) ;

end

Kp0 = zeros(size(Products,1),1); %Indicates the number of countries that produce each product (array
of ubiquity)
```

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```
for i = 1:size(Products,1)

    Kp0(i) = sum(M(:,i)) ;

end


Kc1 = zeros(size(Countries,1),1); %Indicates the next iteration of complexity of each country (array of country complexity 1)

for i = 1:size(Countries,1) %Run through countries

    ComplexitySum = 0;

    for j = 1:size(Products,1) %Run through products

        ComplexitySum = ComplexitySum + M(i,j)*Kp0(j);

    end

    Kc1(i) = ( 1/Kc0(i) ) * ComplexitySum;


end


Kp1 = zeros(size(Products,1),1); %Indicates the next iteration of complexity products (array of product complexity 1)

for i = 1:size(Products,1) %Run through Products

    ComplexitySum = 0;

    for j = 1:size(Countries,1) %Run through Countries

        ComplexitySum = ComplexitySum + M(j,i)*Kc0(j);

    end

    Kp1(i) = ( 1 / Kp0(i) ) * ComplexitySum;

end


Kc2 = zeros(size(Countries,1),1); %Indicates the next iteration of complexity of each country (array of country complexity 1)
Kp2 = zeros(size(Products,1),1); %Indicates the next iteration of complexity products (array of product complexity 1)


for n = 2:NumIters  %Run through number of iterations as required
```

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```
    KcLast = Kc1;
    KpLast = Kp1;

    for i = 1:size(Countries,1) %Run through countries

        ComplexitySum = 0;

        for j = 1:size(Products,1) %Run through products

            ComplexitySum = ComplexitySum + M(i,j)*Kp1(j);

        end

        Kc2(i) = ( 1 / Kc0(i) ) * ComplexitySum;


    end

    Kc1 = Kc2;

    for i = 1:size(Products,1) %Run through Products

        ComplexitySum = 0;

        for j = 1:size(Countries,1) %Run through Countries

            ComplexitySum = ComplexitySum + M(j,i)*Kc1(j);

        end

        Kp2(i) = ( 1 / Kp0(i) ) * ComplexitySum;

    end

    Kp1 = Kp2;

    n;

end
KcN = Kc2;
KpN = Kp2;

CountryCompInd = zeros(size(Countries,1),1);
ProductCompInd = zeros(size(Products,1),1);

for i = 1:size(Countries,1)

    CountryCompInd(i) = ( KcN(i) - mean(KcN(:)) ) / std(KcN(:));

end

for i = 1:size(Products,1)
```

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```
    ProductCompInd(i) = ( KpN(i) - mean(KpN(:)) ) / std(KpN(:));

end


% dlmwrite('CountryComplexity6D.txt',CountryComplexityIndex6D,'precision',10)
% dlmwrite('ProductComplexity6D.txt',ProductComplexityIndex6D,'precision',10)
% dlmwrite('Products6D.txt',Products6D,'precision',6)
% dlmwrite('Countries.txt',Countries)

Progress = 'CalcComplexity_Finish'

end

function [CP,Prox,Centrality] = GenerateCPandProxMat(M,Products,Countries)

Progress = 'GenerateCPandProxMat_Start'

%This code generates:
%1)CP(i,j) -> the conditional probability matrix, .
%       It indicates the probability of an RCA in j given an RCA in i.
%       Its size is CP(Products,Products)

%2)Prox(i,j) -> the matrix of product proximities

%3)Centrality(i,2) a Matrix of ProductCentrality per product (1)
%HsCode; 2) Centrality )

%To Run the code it requires:
%1) M matrix (with 1's and 0's)
%2) Products
%3) Countries

CP = zeros(size(Products,1),size(Products,1)); %Instantiate CP

c = 1; %country number
p1 = 1; %product 1 (i) number
p2 = 1; %product 2 (j) number
CountP1 = 0;
CountP2GivenP1 = 0;

for p1 = 1:size(Products,1) %product 1 (i) number

    for p2 = 1:size(Products,1) %product 2 (j) number

        CountP1 = 0;
        CountP2GivenP1 = 0;

        for c = 1:size(Countries,1) %run through production of all countries for product i and j

            if M(c,p1) == 1
```

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```
                CountP1 = CountP1 + 1;
                if M(c,p2) == 1
                    CountP2GivenP1 = CountP2GivenP1 + 1;
                end
            end
        end
        CP(p1,p2) = CountP2GivenP1/CountP1;
    end
    p1;
end
Prox = CP; %Instantiate Prox equal to CP before minimum mirroring

for p1 = 1:size(Products,1) %product 1 (i) number
   for p2 = 1:size(Products,1) %product 2 (j) number
       if p1 ~= p2
            if Prox(p1,p2) > Prox(p2,p1)
                Prox(p1,p2) = Prox(p2,p1);
            else
                Prox(p2,p1) = Prox(p1,p2);
            end
        end

   end
   p1;
end
Centrality = zeros(size(Products,1),2); %Format = 1) Product; 2) Centrality
Centrality(:,1) = Products(:,1);
```

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```
for i = 1:size(Products,1) %Run through all products

    Centrality(i,2) = (sum(Prox(i,:)) - 1)  / (size(Products,1) - 1) ;

end

%dlmwrite('ProductCentrality6D.txt',ProductCentrality6D,'precision',10)

Progress = 'GenerateCPandProxMat_Finish'

end


function [DistanceAndOpporGain,Densities,Distance,ProxSums] = DistanceAndGain(Prox,RCA,Products,ProductCompInd)

%Progress = 'DistanceAndGain_Start'

%DistanceAndOpporGain:  %1) HsCode; 2) Distance; 3) Distance if opportunity; 4) OpporGain; 5) OpporGain if Opportunity 6) Density; 7) Density if Oppor


% This code creates calculates the "OpenForest" for a country and the
% contribution to open forest of each of the development opportunities at
% the raw data level

% Oppors  Format = (1 HSCodes; 2 Distances; 3 Distance if Unexploited; 4 RCA of Product; 5 Opportunity gain; 6 Adapted Opportunity gain; 7 Densities; 8 Densities if unexploited)

% It creates the intermediate matrixes:
%1) SAPS (1 hscode; 2 RCA)
%2) BelPS (1 hscode; 2 RCA)

%It requires the loading of:
%1) Prox(Products,Products)
%2) SARCAMat ( 1 hs92code; 2 Export of Country; 3 World Export of prduct; 4 SA Good Percentage of world export of good; 5 % SA Good Percentage of SA exports; 6  Good Percentage of world exports; 7 SA RCA)
%3) Products
%4) ProductCompInd

Products;
RCA;  % Format (1 hs92code; SA RCA of good)

Oppors = zeros(size(Products,1),8);
Oppors(:,1) = Products;
Oppors(:,4) = RCA(:,2);

Densities = zeros(size(Products,1),1);
Distance = zeros(size(Products,1),1);
```

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```
CheckSumSA = zeros(size(Products,1),1);
OpenForestContrSum = zeros(size(Products,1),1);
ContributionToOpenForest = zeros(size(Products,1),1);
ContributionToOpenForestSAAdapted = zeros(size(Products,1),1);

%% Calculate Sums Of Proximities per product

ProxSums = zeros(size(Products,1),1);

for i=1:size(Products,1)

    ProxSums(i) = sum(Prox(i,:));

    i;

end


%% Calculate densities; Distance and Open Forest


%Calculate Total Opp value for country:

OpporValue = 0;

for i=1:size(Products,1) % Run through all potential products

    %Calculate SA Densities and Open Forest

    DensityNumerator = 0;
    DistanceNumerator = 0;



    for j=1:size(Products,1) %Run through all columns of the proximity matrix

        if RCA(j,2) > 1 % If you are already competitive; calculate Density from competitive to opportunity otherwise Distance and open forest

            if i ~= j % Make sure product is not not itself

                DensityNumerator = DensityNumerator + Prox(i,j);

            end

        else % Consider other products that could be unlocked from opportunity

            if i ~= j % Make sure product is not not itself

                DistanceNumerator = DistanceNumerator + Prox(i,j);
```

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```
            if RCA(i,2) < 1 % Check if original activity is indeed an opportunity

              OpenForestContrSum(i) = OpenForestContrSum(i) + Prox(i,j)*ProductCompInd(j)/(ProxSums(j) - 1);


            end

          end

        end
    end

%     CheckSumSA(i) = CheckSumSA(i) / (sum(Prox6D(i,:)) - 1);

    Densities(i) = DensityNumerator / (ProxSums(i) - 1);
    Distance(i) = DistanceNumerator / (ProxSums(i) - 1);



    ContributionToOpenForest(i) = OpenForestContrSum(i) - Densities(i)* ProductCompInd(i);
    ContributionToOpenForestSAAdapted(i) = OpenForestContrSum(i);


    Oppors(i,2) = Distance(i,1);

    Oppors(i,5) = ContributionToOpenForest(i);
    Oppors(i,6) = ContributionToOpenForestSAAdapted(i);
    Oppors(i,7) = Densities(i);

    if RCA(i,2) <= 1 % If opportunity not exploited yet, add to unexploited column

      Oppors(i,8) = Oppors(i,7);
      Oppors(i,3) = Oppors(i,2);

      OpporValue = OpporValue + Densities(i) * ProductCompInd(i);

    end




    i; %Keep track of execution

end

% UnitySA = CheckSumSA + SADensities6D;
% UnityBel = CheckSumBel + BelDensities6D;

DistanceAndOpporGain = Oppors(:,[1,2,3,5,6,7,8]);   %1) HsCode; 2) Distance; 3) Distance if opportunity; 4) OpporGain; 5) OpporGain if Opportunity 6) Density; 7) Density if Oppor
```

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```
% dlmwrite('DensitiesAndOpenForestSA6D.txt',DensitiesAndOpenForestSA6D,'precision',10)

%Progress = 'DistanceAndGain_Finish'


end

function [OpporValue] = OpporValue(Prox,RCA,Products,ProductCompInd,ProxSums)

%DistanceAndOpporGain:  %1) HsCode; 2) Distance; 3) Distance if opportunity; 4) OpporGain; 5)
OpporGain if Opportunity 6) Density; 7) Density if Oppor
% This code calculates the "OpenForest" / Opportunity value for a country

Densities = zeros(size(Products,1),1);


%% Calculate densities; Distance and Open Forest


%Calculate Total Opp value for country:

OpporValue = 0;

for i=1:size(Products,1) % Run through all potential products

  if RCA(i,2) <= 1 % If opportunity not exploited yet

    DensityNumerator = 0;

    for j=1:size(Products,1) %Run through all columns of the proximity matrix

      if RCA(j,2) > 1 % If you are already competitive; calculate Density from competitive to
opportunity

        if i ~= j % Make sure product is not not itself

          DensityNumerator = DensityNumerator + Prox(i,j);

        end

      end
    end

    Densities(i) = DensityNumerator / (ProxSums(i) - 1);


    %if RCA(i,2) <= 1 % If opportunity not exploited yet, add to unexploited column

    OpporValue = OpporValue + Densities(i) * ProductCompInd(i);

  end
```

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```
end


end

function [GVCFull,GVCAct,GVCTier] = GVCDistanceAndGain(DistanceAndOpporGain,ProductCompInd,GVCData,Products,SARCAMat,Densities)

%Progress = 'GVCDistanceAndGain_Start'

%This code sums the distance,OpporGain and Compxlity index metrics for each
%of the value chain steps. It also distinguishes parts of each VC activity
%for which a competitive advante already exists and for those tha are still
%opportunities.

%Output:
%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition
%GVCAct 1) Tier#; 2) GVC Activity ;3) Avg Complexity; 4) Avg Density; 5) Avg RCA; 6) Avg Complexity if Opp; 7) Avg Distance if Opportunity; 8) Avg OpporGain if Opportunity; 9) Avg RCA if Opp; 10) SA export of Activity; 11) World export of activity; 12) SA export if oppor; 13) World export if opp; 14) # of Products In Activity ; 15) # of Opp Products in Act
%GVCTier 1) Tier#; 2) Avg Complexity; 3) Avg Density; 4) Avg RCA; 5) Avg Complexity if Opp; 6) Avg Distance if Opportunity; 7) Avg OpporGain if Opportunity; 8) Avg RCA if Opp; 9) SA export of Activity; 10) World export of activity; 11) SA export if oppor; 12) World export if opp; 13) Number Act in Tier; 14) Number of Opp Act in Tier

%It requires
%1) DistanceAndOpporGain %1) HsCode; 2) Distance; 3) Distance if opportunity; 4) OpporGain; 5) OpporGain if Opportunity 6) Density; 7) Density if Oppor
%2) ProductCompInd
%3) GVCData 1) Tier#; 2) GVC Activity#; 3) HS Code
%4) Products
%5) Centrality 1) HS Code 2) Centrality
%6) SARCAMat 1) hs92code; 2) Export of Country; 3) World Export of product; 4) SA Good Percentage of world export of good; 5) SA Good Percentage of SA exports; 6)  Good Percentage of world exports; 7) SA RCA

NumberGVCTiers = size(unique(GVCData(:,1)),1);
NumberGVCActivities = size(unique(GVCData(:,2)),1);
NumberGVCProducts = size(unique(GVCData(:,3)),1);

NumberProductsInAct = zeros(NumberGVCActivities(1),1);
NumberActInTier = zeros(NumberGVCTiers(1),1);
NumberProdInTier = zeros(NumberGVCTiers(1),1);

NumberOppProductsInAct = zeros(NumberGVCActivities(1),1);
NumberOppActInTier = zeros(NumberGVCTiers(1),1);
NumberOppProdInTier = zeros(NumberGVCTiers(1),1);
```

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```
GVCFull = zeros(NumberGVCProducts(1),15);
GVCAct = zeros(NumberGVCActivities(1),15);
GVCTier = zeros(NumberGVCTiers(1),14);

%% Concatenate

for i = 1:size(GVCData,1) %Step through all GVCData components



    HSCodePosition = find(Products==GVCData(i,3));

    GVCFull(i,15) = HSCodePosition; %Record link to product

    GVCFull(i,[1,2,3]) = GVCData(i,[1,2,3]); % Copy basic variables
    GVCFull(i,4) = ProductCompInd(HSCodePosition); %Copy complexity
    GVCFull(i,5) = Densities(HSCodePosition); %Copy Densities
    GVCFull(i,6) = SARCAMat(HSCodePosition,7); %Copy RCA

    GVCFull(i,[11,12]) = SARCAMat(HSCodePosition,[2,3]); %Copy SA and World export of
activity

    Act = GVCFull(i,2); %Check which activity is being dealt with
    NumberProductsInAct(Act,1) = NumberProductsInAct(Act,1) + 1; %Count number of products in
act

    if GVCFull(i,6) < 1 %Copy if opportunity.

        GVCFull(i,[7,10,13,14]) = GVCFull(i,[4,6,11,12]); %Copy complexity, RCA if opportunity and
export if opp
        GVCFull(i,[8,9]) = DistanceAndOpporGain(HSCodePosition,[3,5]); %Copy Distance and
opportunity Gain if opp
        NumberOppProductsInAct(Act) = NumberOppProductsInAct(Act) + 1; %Count number of
products in act

    end

end

GVCAct(:,14) = NumberProductsInAct(:,1);
GVCAct(:,15) = NumberOppProductsInAct(:,1);

%% Sum trade total and for if opportunity for weighting to sum to GVCACT and GVCTier

for i = 1:size(GVCData,1) %Step through all GVCData components

    j = GVCFull(i,2); % Activity
    k = GVCFull(i,1); % Tier

    GVCAct(j,1) = k; %Populate Tier
    GVCAct(j,2) = j; %Populate activity
```

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```
    GVCTier(k,1) = k;

    GVCAct(j,[10,11,12,13]) = GVCAct(j,[10,11,12,13]) + GVCFull(i,[11,12,13,14]); %Copy trade
    GVCTier(k,[9,10,11,12]) = GVCTier(k,[9,10,11,12]) + GVCFull(i,[11,12,13,14]); %Copy trade


end



%% Use trade weighting for summing to Act (Do not weight for trade)

for i = 1:size(GVCData,1) %Step through all GVCData components

    j = GVCFull(i,2); % Activity

    GVCAct(j,[3,4,5]) = GVCAct(j,[3,4,5]) + GVCFull(i,[4,5,6]) ./ NumberProductsInAct(j);  % Copy those that are average for all products that are part of activity
    GVCAct(j,[6,7,8,9]) = GVCAct(j,[6,7,8,9]) + GVCFull(i,[7,8,9,10]) ./ NumberOppProductsInAct(j);   % Copy those that are average for opportunities (weighted only according to opportunities' export)


%   GVCAct(j,[3,4,5]) = GVCAct(j,[3,4,5]) + GVCFull(i,[4,5,6]) .* GVCFull(i,12) ./ GVCAct(j,11);  % Copy those that are average for all products that are part of activity
%       GVCAct(j,[6,7,8,9]) = GVCAct(j,[6,7,8,9]) + GVCFull(i,[7,8,9,10]) .* GVCFull(i,14) ./ GVCAct(j,13);   % Copy those that are average for opportunities (weighted only according to opportunities' export)

%         GVCTier(k,[2,3,4]) = GVCTier(k,[2,3,4]) + GVCFull(i,[4,5,6]) .* GVCFull(i,12) ./ GVCTier(k,10);  % Copy those that are average for all products that are part of activity
%       GVCTier(k,[5,6,7,8]) = GVCTier(k,[5,6,7,8]) + GVCFull(i,[7,8,9,10]) .* GVCFull(i,14) ./ GVCTier(k,12);   % Copy those that are average for opportunities (weighted only according to opportunities' export)

end


%% Count number of products per tier

for i = 1:size(GVCFull,1)

    Tier = GVCFull(i,1);
    NumberProdInTier(Tier) = NumberProdInTier(Tier) + 1;

    RCAForProd = GVCFull(i,6);

    if RCAForProd < 1

        NumberOppProdInTier(Tier) = NumberOppProdInTier(Tier) + 1;

    end
```

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```
end

% GVCTier(:,13) = NumberActInTier(:,1);
% GVCTier(:,14) = NumberOppActInTier(:,1);



%% Count number of activities per tier

for i = 1:size(GVCAct,1)

    Tier = GVCAct(i,1);
    NumberActInTier(Tier) = NumberActInTier(Tier) + 1;

    RCAForAct = GVCAct(i,5);

    if RCAForAct < 1

        NumberOppActInTier(Tier) = NumberOppActInTier(Tier) + 1;

    end

end

GVCTier(:,13) = NumberActInTier(:,1);
GVCTier(:,14) = NumberOppActInTier(:,1);

%% Use trade weighting for summing to Tier (Do not weight for trade)

for i = 1:size(GVCFull,1) %Step through all GVCFull components

    k = GVCFull(i,1); % Tier

    GVCTier(k,[2,3,4]) = GVCTier(k,[2,3,4]) + GVCFull(i,[4,5,6]) ./ NumberProdInTier(k);  % Copy those that are average for all products that are part of activity
    GVCTier(k,[5,6,7,8]) = GVCTier(k,[5,6,7,8]) + GVCFull(i,[7,8,9,10]) ./ NumberOppProdInTier(k);  % Copy those that are average for opportunities (weighted only according to opportunities' export)

end

% Progress = 'GVCDistanceAndGain_Finish'


end


function [P2AllP,P2P,A2A,T2T,PercInGVCProd,PercInGVCAct,PercInGVCTier] = CalcGVCProximities(GVCFull,GVCAct,GVCTier,Prox,Products)

Progress = 'CalcGVCProximities_Start'
```

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```
%This function evaluates the proximities between products that form part of the GVC

%It generates various matrixes:
%P2AllP (Dimensions 1: GVCProd#; Dimensions 2: AllProducts#)(this array has all the proximities of GVC products to all the other products)
%P2P (Dimensions 1: GVCProd#; Dimensions 2: GVCProd#)(this array has all the proximities of GVC products to all the other GVC products )
%A2A (Dimensions 1: GVCAct#; Dimensions 2: GVCAct#)(this array has all the proximities of GVC activities to all the other GVC activities)
%T2T (Dimensions 1: GVCTier#; Dimensions 2: GVCTier#)(this array has all the proximities of GVC activities to all the other GVC activities)

%It requires the following matrixes:
%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition
%GVCAct 1) Tier# 2) GVC Activity 3) Avg Complexity; 4) Avg Density; 5) Avg RCA; 6) Avg Complexity if Opp; 7) Avg Distance if Opportunity; 8) Avg OpporGain if Opportunity; 9) Avg RCA if Opp; 10) SA export of Activity; 11) World export of activity; 12) SA export if oppor; 13) World export if opp; 14) # of Products In Activity ; 15) # of Opp Products in Act
%GVCTier 1) Tier# 2) Avg Complexity; 3) Avg Density; 4) Avg RCA; 5) Avg Complexity if Opp; 6) Avg Distance if Opportunity; 7) Avg OpporGain if Opportunity; 8) Avg RCA if Opp; 9) SA export of Activity; 10) World export of activity; 11) SA export if oppor; 12) World export if opp; 13) Number Act in Tier; 14) Number of Opp Act in Tier

%Prox(i,j) -> the matrix of product proximities
%Products

NumberGVCTiers = size(GVCTier,1);
NumberGVCActivities = size(GVCAct,1);
NumberGVCProducts = size(GVCFull,1);
NumberProducts = size(Products,1);

P2AllP = zeros(NumberGVCProducts,NumberProducts);
P2P = zeros(NumberGVCProducts,NumberGVCProducts);
A2A = zeros(NumberGVCActivities,NumberGVCActivities);
A2ANumer = zeros(NumberGVCActivities,NumberGVCActivities);
A2ADenom = zeros(NumberGVCActivities,NumberGVCActivities);
T2T = zeros(NumberGVCTiers,NumberGVCTiers);
T2TNumer = zeros(NumberGVCTiers,NumberGVCTiers);
T2TDenom = zeros(NumberGVCTiers,NumberGVCTiers);
% PercInGVCProd = zeros(NumberGVCProducts,1);
% PercInGVCAct = zeros(NumberGVCActivities,1);
% PercInGVCTier = zeros(NumberGVCTiers,1);
ProductCodePositions = zeros(NumberGVCProducts,1);
AllProxAct = zeros(NumberGVCActivities,1);
AllProxTier = zeros(NumberGVCTiers,1);
ProxActInGVC = zeros(NumberGVCActivities,1);
ProxTierInGVC = zeros(NumberGVCTiers,1);
SumProxProductAll = zeros(NumberGVCProducts,1);
```

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```
SumProxProductInGVC = zeros(NumberGVCProducts,1);

for i = 1:NumberGVCProducts

   ProductCodePositions(i) = find(Products==GVCFull(i,3));

end

%% Populate P2AllP, P2P and count Proximities within each product, activitiy and tier in relation to total

for i = 1:NumberGVCProducts

   ActNum1 = GVCFull(i,2);
   TierNum1 = GVCFull(i,1);

   ProductCode1Pos =  ProductCodePositions(i); %Capture product code for activity in GVC

   P2AllP(i,:) = Prox(ProductCode1Pos,:); %Transfer all proximities for all products

   for j = 1:NumberGVCProducts %Transfer only proximities for products in the GVC

      ProductCode2Pos = ProductCodePositions(j);

      P2P(i,j) = Prox(ProductCode1Pos,ProductCode2Pos);

   end

   SumProxProductAll(i) = sum(P2AllP(i,:)) - 1;
   SumProxProductInGVC(i) = sum(P2P(i,:)) - 1;

   AllProxAct(ActNum1) = AllProxAct(ActNum1) + SumProxProductAll(i);
   AllProxTier(TierNum1) = AllProxTier(TierNum1) + SumProxProductAll(i);

   ProxActInGVC(ActNum1) = ProxActInGVC(ActNum1) + SumProxProductInGVC(i);
   ProxTierInGVC(TierNum1) = ProxTierInGVC(TierNum1) + SumProxProductInGVC(i);

end

%% Populate PercInGVC

PercInGVCProd = SumProxProductInGVC ./ SumProxProductAll; %Calculate the % of proximities that are captured within the GVC
PercInGVCAct =  ProxActInGVC ./ AllProxAct; %Calculate the % of proximities that are captured within the GVC
PercInGVCTier = ProxTierInGVC ./ AllProxTier; %Calculate the % of proximities that are captured within the GVC

%% Populate A2A (Not weighting by trade)

for i = 1:NumberGVCProducts
```

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```
    ActNum1 = GVCFull(i,2);

    for j = 1:NumberGVCProducts

        ActNum2 = GVCFull(j,2);

        A2ANumer(ActNum1,ActNum2) = A2ANumer(ActNum1,ActNum2) + P2P(i,j) ;
        A2ADenom(ActNum1,ActNum2) = A2ADenom(ActNum1,ActNum2) + 1 ;

        %A2A(ActNum1,ActNum2) = A2A(ActNum1,ActNum2) + P2P(i,j); %.* GVCFull(i,12) ./ GVCAct(j,11);

    end

end

A2A = A2ANumer ./ A2ADenom;

%% Populate T2T

for i = 1:NumberGVCActivities

    TierNum1 = GVCAct(i,1);

    for j = 1:NumberGVCActivities

        TierNum2 = GVCAct(j,1);

        T2TNumer(TierNum1,TierNum2) = T2TNumer(TierNum1,TierNum2) + A2A(i,j);
        T2TDenom(TierNum1,TierNum2) = T2TDenom(TierNum1,TierNum2) + 1;

    end

end

T2T = T2TNumer ./ T2TDenom;

Progress = 'CalcGVCProximities_Finish'


end

function [BaseLineMetrics] = CalcBaselineMetrics(Prox,RCA,Products,ProductCompInd,ProxSums,GVCFull,DistanceAndOpporGain,SARCAMat)

BaseLineMetrics = zeros(9,1); % 1) Opportunity Value; 2) Average complexity of products within the value chain with RCA > 1; 3) Avg distance to Products in the VC with RCA < 1; 4) Average complexity of products within the PS with RCA > 1; 5) Average distance to products in the product space with RCA <1; 6) Num in GVC; 7) Sum of complexity in GVC; 8) Num in PS; 9) Sum of complexity in PS
```

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```
BaseLineMetrics(1) = OpporValue(Prox,RCA,Products,ProductCompInd,ProxSums);
[BaseLineMetrics(2),BaseLineMetrics(3),BaseLineMetrics(6),BaseLineMetrics(7)] =
VCCompAndDist(GVCFull);
[BaseLineMetrics(4),BaseLineMetrics(5),BaseLineMetrics(8),BaseLineMetrics(9)] =
PSCompAndDist(DistanceAndOpporGain,ProductCompInd,SARCAMat);

end

function [CompInVC,AvgDistToProdInVC,NumberInVC,SumCompInVC] =
VCCompAndDist(GVCFull)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7)
Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA
Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp;
15) ProdPosition

SumCompInVC = 0;
NumberInVC = 0;

SumDistToVC = 0;
NumberCurOutVC = 0;

for i = 1:size(GVCFull,1)

   if GVCFull(i,6) > 1 %Calculate avg complexity of products withing the VC with RCA > 1

      SumCompInVC = SumCompInVC + GVCFull(i,4);
      NumberInVC = NumberInVC + 1;

   else % Calculate avg Distance to products in the VC with RCA < 1

      SumDistToVC = SumDistToVC + GVCFull(i,8);
      NumberCurOutVC = NumberCurOutVC + 1;

   end

end

CompInVC = SumCompInVC / NumberInVC;
AvgDistToProdInVC = SumDistToVC / NumberCurOutVC;

end

function [CompInPS,DistToPS,NumberWithRCA,SumCompInPS] =
PSCompAndDist(DistanceAndOpporGain,ProductCompInd,SARCAMat)

%1) DistanceAndOpporGain %1) HsCode; 2) Distance; 3) Distance if opportunity; 4) OpporGain; 5)
OpporGain if Opportunity 6) Density; 7) Density if Oppor
%2) ProductCompInd
%6) SARCAMat 1) hs92code; 2) Export of Country; 3) World Export of product; 4) SA Good
Percentage of world export of good; 5) SA Good Percentage of SA exports; 6)  Good Percentage of
world exports; 7) SA RCA
```

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```
SumCompInPS = 0;
NumberWithRCA = 0;

SumDistToPS = 0;
NumberCurOutPS = 0;

for i = 1:size(ProductCompInd,1)

   if SARCAMat(i,7) > 1 %Calculate avg complexity of products within the PS with RCA > 1

      SumCompInPS = SumCompInPS + ProductCompInd(i);
      NumberWithRCA = NumberWithRCA + 1;

   else % Calculate avg Distance to products in the PS with RCA < 1

      SumDistToPS = SumDistToPS + DistanceAndOpporGain(i,2);
      NumberCurOutPS = NumberCurOutPS + 1;

   end

end

CompInPS = SumCompInPS / NumberWithRCA;
DistToPS = SumDistToPS / NumberCurOutPS;

end

function [BaseRCASpace] = CalculateBaseRCASpace(RCA)

BaseRCASpace = zeros(size(RCA,1),1);
SetRCATo = 1.1;

for i = 1:size(RCA,1)

   if RCA(i,2) > 1

      BaseRCASpace(i,1) = SetRCATo;

   end

end

end

function [GVCFullBaseRCA] = CalculateGVCFullBase(GVCFull) %Normalise current GVC Full

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition
```

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```
GVCFullBaseRCA = zeros(size(GVCFull,1),1);
SetRCATo = 1.1;

for i = 1:size(GVCFull,1)

   if GVCFull(i,6) > 1

      GVCFullBaseRCA(i,1) = SetRCATo;

   end

end

end

function [GVCRCAScenarioCont] = CalcGVCRCASpaceScenarioCont(GVCFull,GVCAct,Products)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition

NumGVCAct = size(GVCAct,1);
NumProduct = size(Products,1);

GVCRCAScenarioCont = zeros(NumGVCAct,NumProduct);

SetRCATo = 1.1;

for i = 1:size(GVCFull,1)  %Run through all RCA's in GVCFull

   if GVCFull(i,6) < 1 %Consider All those for which RCA < 1 (i.e. Populate all those in activity for which RCA not currently > 1)

       GVCRCAScenarioCont(GVCFull(i,2),GVCFull(i,15)) = SetRCATo;


   end

end

end

function [GVCFullRCAScenarioCont] = CalcGVCFullRCAScenarioCont(GVCFull,GVCAct) % Calculate raw contributions for each activity

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition
```

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```
NumGVCAct = size(GVCAct,1);
NumInGVCFull = size(GVCFull,1);

GVCFullRCAScenarioCont = zeros(NumGVCAct,NumInGVCFull);

SetRCATo = 1.1;

for i = 1:size(GVCFull,1)  %Run through all RCA's in GVCFull

   if GVCFull(i,6) < 1 %Consider All those for which RCA < 1 (i.e. Populate all those in activity for which RCA not currently > 1)

       GVCFullRCAScenarioCont(GVCFull(i,2),i) = SetRCATo;

   end

end

end

function [GVCRCAScenarios1] = CalcGVCRCASpaceScenarios1(GVCRCAScenarioCont,BaseRCASpace,GVCAct,Products)

%GVCRCAScenarioCont: (NumGVCAct,NumProduct);
%BaseRCASpace = 1) RCA per product;

NumGVCAct = size(GVCAct,1);
NumProducts = size(Products,1);

GVCRCAScenarios1 = zeros(NumGVCAct,NumProducts);

for i = 1:NumGVCAct

   GVCRCAScenarios1(i,:) = transpose(BaseRCASpace) + GVCRCAScenarioCont(i,:);

end

end

function [GVCFullRCAScenarios1] = CalcGVCFullRCAScenarios1(GVCFullRCAScenarioCont,GVCFullBaseRCA,GVCAct,GVCFull)

%GVCRCAScenarioCont: (NumGVCAct,NumProduct = RCA);
%BaseRCASpace = 1) RCA per product;

NumGVCAct = size(GVCAct,1);
NumInGVCFull = size(GVCFull,1);

GVCFullRCAScenarios1 = zeros(NumGVCAct,NumInGVCFull);

for i = 1:NumGVCAct
```

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```
    GVCFullRCAScenarios1(i,:) = transpose(GVCFullBaseRCA) + GVCFullRCAScenarioCont(i,:);

end

end

function [GVCRCAScenarios2] = CalcGVCRCASpaceScenarios2(GVCRCAScenarioCont,BaseRCASpace,GVCAct,Products)

%GVCRCAScenarioCont: (NumGVCAct,NumProduct);
%BaseRCASpace = 1) RCA per product;

NumGVCAct = size(GVCAct,1);
NumProducts = size(Products,1);

GVCRCAScenarios2 = zeros(NumGVCAct,NumGVCAct,NumProducts);

for i = 1:NumGVCAct

    for j = 1:NumGVCAct

        GVCRCAScenarios2(i,j,:) = transpose(BaseRCASpace) + GVCRCAScenarioCont(i,:) + GVCRCAScenarioCont(j,:);

    end

end

end

function [GVCFullRCAScenarios2] = CalcGVCFullRCAScenarios2(GVCFullRCAScenarioCont,GVCFullBaseRCA,GVCAct,GVCFull)

%GVCRCAScenarioCont: (NumGVCAct,NumProduct);
%BaseRCASpace = 1) RCA per product;

NumGVCAct = size(GVCAct,1);
NumInGVCFull = size(GVCFull,1);

GVCFullRCAScenarios2 = zeros(NumGVCAct,NumGVCAct,NumInGVCFull);

for i = 1:NumGVCAct

    for j = 1: NumGVCAct

        GVCFullRCAScenarios2(i,j,:) = transpose(GVCFullBaseRCA) + GVCFullRCAScenarioCont(i,:) + GVCFullRCAScenarioCont(j,:);

    end

end
```

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```
end

function [GVCRCAScenarios3] = CalcGVCRCASpaceScenarios3(GVCRCAScenarioCont,BaseRCASpace,GVCAct,Products)

%GVCRCAScenarioCont: (NumGVCAct,NumProduct);
%BaseRCASpace = 1) RCA per product;

NumGVCAct = size(GVCAct,1);
NumProducts = size(Products,1);

GVCRCAScenarios3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,NumProducts);

for i = 1:NumGVCAct

   for j = 1:NumGVCAct

      for k = 1:NumGVCAct

         GVCRCAScenarios3(i,j,k,:) = transpose(BaseRCASpace) + GVCRCAScenarioCont(i,:) + GVCRCAScenarioCont(j,:) + GVCRCAScenarioCont(k,:);

      end

   end

end

end

function [GVCFullRCAScenarios3] = CalcGVCFullRCAScenarios3(GVCFullRCAScenarioCont,GVCFullBaseRCA,GVCAct,GVCFull)

%GVCRCAScenarioCont: (NumGVCAct,NumProduct);
%BaseRCASpace = 1) RCA per product;

NumGVCAct = size(GVCAct,1);
NumInGVCFull = size(GVCFull,1);

GVCFullRCAScenarios3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,NumInGVCFull);

for i = 1:NumGVCAct

   for j = 1:NumGVCAct

      for k = 1:NumGVCAct

         GVCFullRCAScenarios3(i,j,k,:) = transpose(GVCFullBaseRCA) + GVCFullRCAScenarioCont(i,:) + GVCFullRCAScenarioCont(j,:) + GVCFullRCAScenarioCont(k,:);

      end
```

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```
    end

end

end

function [ComplexityInVCScenarios SumCompContr NumberInActToBeAdded] = CalcCompContr(GVCFull,GVCAct,NumProductsCurInGVC,CurrentSumOfComplexityInGVC)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition

NumGVCAct = size(GVCAct,1);

SumCompContr = zeros(NumGVCAct,1); % 1) ContToComp (per activity)

NumberInActToBeAdded = zeros(NumGVCAct,1); % 1) NumInActivity (per activity)

%ComplexityInVCScenarios = zeros(NumGVCAct,1); % 1) Complexity In VC for scenario (per activity)


for i = 1:size(GVCFull,1)  %Run through all RCA's in GVCFull

    if GVCFull(i,6) < 1 %Consider All those for which RCA < 1 (i.e. Populate all those in activity for which RCA not currently > 1)

        SumCompContr(GVCFull(i,2),1) = SumCompContr(GVCFull(i,2),1) + GVCFull(i,4); %Sum complexity for activity
        NumberInActToBeAdded(GVCFull(i,2),1) = NumberInActToBeAdded(GVCFull(i,2),1) + 1;

    end

end

ComplexityInVCScenarios = (SumCompContr + CurrentSumOfComplexityInGVC) ./ (NumberInActToBeAdded + NumProductsCurInGVC);

end

function [Comp2] = CalcCompContr2(GVCAct,NumProductsCurInGVC,CurrentSumOfComplexityInGVC,SumCompContr,NumberInActToBeAdded)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition
```

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```
NumGVCAct = size(GVCAct,1);

TotalSumCompCont = zeros(NumGVCAct,NumGVCAct,1); % 1) ContToComp (per activity)

TotalNumberInActToBeAdded = zeros(NumGVCAct,NumGVCAct,1); % 1) NumInActivity (per activity)

Comp2 = zeros(NumGVCAct,NumGVCAct,1); % 1) Complexity In VC for scenario (per activity)

for i = 1:NumGVCAct

   for j = 1:NumGVCAct

      if i ~= j

         TotalSumCompCont(i,j) = SumCompContr(i) + SumCompContr(j);
         TotalNumberInActToBeAdded(i,j) = NumberInActToBeAdded(i) + NumberInActToBeAdded(j);

         Comp2(i,j) = (TotalSumCompCont(i,j) + CurrentSumOfComplexityInGVC) ./ (TotalNumberInActToBeAdded(i,j) + NumProductsCurInGVC);

      end

   end

end

%ComplexityInVCScenarios2 = (SumCompContr + CurrentSumOfComplexityInGVC) ./ (NumberInActToBeAdded + NumProductsCurInGVC);

end

function [Comp3] = CalcCompContr3(GVCAct,NumProductsCurInGVC,CurrentSumOfComplexityInGVC,SumCompContr,NumberInActToBeAdded)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition

NumGVCAct = size(GVCAct,1);

TotalSumCompCont = zeros(NumGVCAct,NumGVCAct,NumGVCAct,1); % 1) ContToComp (per activity)

TotalNumberInActToBeAdded = zeros(NumGVCAct,NumGVCAct,NumGVCAct,1); % 1) NumInActivity (per activity)

Comp3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,1); % 1) Complexity In VC for scenario (per activity)
```

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```
for i = 1:NumGVCAct

   for j = 1:NumGVCAct

      if i ~= j

         for k = 1:NumGVCAct

            if (k ~= j) && (k ~= i)

               TotalSumCompCont(i,j,k) = SumCompContr(i) + SumCompContr(j) + SumCompContr(k);
               TotalNumberInActToBeAdded(i,j,k) = NumberInActToBeAdded(i) + NumberInActToBeAdded(j) + NumberInActToBeAdded(k);

               Comp3(i,j,k) = (TotalSumCompCont(i,j,k) + CurrentSumOfComplexityInGVC) ./ (TotalNumberInActToBeAdded(i,j,k) + NumProductsCurInGVC);

            end

         end

      end

   end

end

%ComplexityInVCScenarios2 = (SumCompContr + CurrentSumOfComplexityInGVC) ./ (NumberInActToBeAdded + NumProductsCurInGVC);

end

function [DistReq1] = CalcDist1(GVCFull,GVCAct)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition

NumGVCAct = size(GVCAct,1);

DistReq1 = zeros(NumGVCAct,1); % 1) DistReq1 (per activity)


for i = 1:size(GVCFull,1)  %Run through all RCA's in GVCFull

   if GVCFull(i,6) < 1 %Consider All those for which RCA < 1 (i.e. Populate all those in activity for which RCA not currently > 1)
```

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```
        DistReq1(GVCFull(i,2),1) = DistReq1(GVCFull(i,2),1) + GVCFull(i,8); %Sum distances (only valid for first iter)

    end

end

end

function [DistReq2] = CalcDist2(GVCFull,GVCAct,GVCFullRCAScenarios1,GVCRCAScenarios1,ProxSums,DistReq1,Products,Prox)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition

%GVCFullRCAScenarios1 = zeros(NumGVCAct,NumInGVCFull = RCA);
%GVCRCAScenarios1 = zeros(NumGVCAct,NumProducts);

NumGVCAct = size(GVCAct,1);
SizeGVCFull = size(GVCFull,1);

TotalDistances2 = zeros(NumGVCAct,NumGVCAct,1);
Distances2GVCFull = zeros(NumGVCAct,SizeGVCFull,1);

for ActAlreadyTaken = 1:NumGVCAct % Run through different scenarios from which is being worked

    for i=1:size(GVCFull,1) % Run through all potential products in VC to which distances must be calculated

        if GVCFullRCAScenarios1(ActAlreadyTaken,i) < 1  % If activity still an opportunity, calculate distance to it.

            DistanceNumerator = 0;

            for j=1:size(Products,1) %Run through all columns of the proximity matrix (i.e. all activities to the product in the VC)

                if GVCRCAScenarios1(ActAlreadyTaken,j) < 1 % If you do not yet have a competitive advantage in other products, the distance increases

                    if GVCFull(i,15) ~= j % Make sure product is not not itself

                        DistanceNumerator = DistanceNumerator + Prox(GVCFull(i,15),j);

                    end

                end
            end
```

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```
            Distances2GVCFull(ActAlreadyTaken,i) = DistanceNumerator / (ProxSums(GVCFull(i,15))
- 1);

        end

    end

end

Distance2InVC = zeros(NumGVCAct,NumGVCAct,1);

for i = 1:NumGVCAct % Run through all scenarios

    for j = 1:SizeGVCFull % Run Through All Distances

        Distance2InVC(i,GVCFull(j,2)) = Distance2InVC(i,GVCFull(j,2)) + Distances2GVCFull(i,j);

    end

end


for i = 1:NumGVCAct %Run through all scenario 1s

    for j = 1:NumGVCAct %Run through all scenario 2s

        TotalDistances2(i,j) = Distance2InVC(i,j) + DistReq1(i);

    end

end

%dlmwrite('TotalDistances2.txt',TotalDistances2,'precision',10);

DistReq2 = TotalDistances2;


end

function [DistReq3] =
CalcDist3(GVCFull,GVCAct,GVCFullRCAScenarios2,GVCRCAScenarios2,ProxSums,DistReq1,
DistReq2,Products,Prox)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7)
Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA
Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp;
15) ProdPosition

%GVCFullRCAScenarios1 = zeros(NumGVCAct,NumInGVCFull = RCA);
%GVCRCAScenarios1 = zeros(NumGVCAct,NumProducts);
```

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```
NumGVCAct = size(GVCAct,1);
SizeGVCFull = size(GVCFull,1);

TotalDistances3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,1);
Distances3GVCFull = zeros(NumGVCAct,NumGVCAct,SizeGVCFull,1);

for Act1AlreadyTaken = 1:NumGVCAct % Run through different scenarios from which is being worked

   for Act2AlreadyTaken = 1:NumGVCAct % Run through different scenarios from which is being worked

      for i=1:size(GVCFull,1) % Run through all potential products in VC to which distances must be calculated

         if GVCFullRCAScenarios2(Act1AlreadyTaken,Act2AlreadyTaken,i) < 1  % If activity still an opportunity, calculate distance to it.

            DistanceNumerator = 0;

            for j=1:size(Products,1) %Run through all columns of the proximity matrix (i.e. all activities to the product in the VC)

               if GVCRCAScenarios2(Act1AlreadyTaken,Act2AlreadyTaken,j) < 1 % If you do not yet have a competitive advantage in other products, the distance increases

                  if GVCFull(i,15) ~= j % Make sure product is not not itself

                     DistanceNumerator = DistanceNumerator + Prox(GVCFull(i,15),j);

                  end

               end
            end

            Distances3GVCFull(Act1AlreadyTaken,Act2AlreadyTaken,i) = DistanceNumerator / (ProxSums(GVCFull(i,15)) - 1);

         end

      end

   end

end

Distance3InVC = zeros(NumGVCAct,NumGVCAct,NumGVCAct,1);

for i = 1:NumGVCAct % Run through all scenarios

   for j = 1:NumGVCAct % Run through all scenarios
```

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```
    for k = 1:SizeGVCFull % Run Through All Distances

      Distance3InVC(i,j,GVCFull(k,2)) = Distance3InVC(i,j,GVCFull(k,2)) + Distances3GVCFull(i,j,k);

    end

  end

end


for i = 1:NumGVCAct %Run through all scenario 1s

  for j = 1:NumGVCAct %Run through all scenario 2s

    for k = 1:NumGVCAct %Run through all scenario 3s

      TotalDistances3(i,j,k) = Distance3InVC(i,j,k) + DistReq1(i) + DistReq2(j);

    end

  end

end

%dlmwrite('TotalDistances2.txt',TotalDistances2,'precision',10);

DistReq3 = TotalDistances3;


end

function OpporValScenarios1 = CalcOppValScenarios1(Products,Prox,ProductCompInd,GVCRCAScenarios1,GVCAct,BaseRCASpace,ProxSums)

OpporVal1Time = tic;

NumGVCAct = size(GVCAct,1);
OpporValScenarios1 = zeros(NumGVCAct,1); %1) ContToComp (per activity)
Densities = zeros(size(Products,1),1);

ScenarioRCA = zeros(size(BaseRCASpace));

for Act = 1:NumGVCAct

  ScenarioRCA = GVCRCAScenarios1(Act,:); %+ transpose(BaseRCASpace);

  for i=1:size(Products,1) % Run through all potential products

    if ScenarioRCA(i) <= 1 % If opportunity not exploited yet
```

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```
        DensityNumerator = 0;

        for j=1:size(Products,1) %Run through all columns of the proximity matrix

          if ScenarioRCA(j) > 1 % If you are already competitive; calculate Density from competitive to opportunity

            if i ~= j % Make sure product is not not itself

              DensityNumerator = DensityNumerator + Prox(i,j);

            end

          end
        end

        Densities(i) = DensityNumerator / (ProxSums(i) - 1);

        %if RCA(i,2) <= 1 % If opportunity not exploited yet, add to unexploited column

        OpporValScenarios1(Act) = OpporValScenarios1(Act) + Densities(i) * ProductCompInd(i);

      end

  end

end

OpporVal1Timed = toc(OpporVal1Time)

end

function OpporValScenarios2 = CalcOppValScenarios2(Products,Prox,ProductCompInd,GVCRCAScenarios2,GVCAct,BaseRCASpace,ProxSums)

OpporVal2Time = tic;

%GVCRCAScenarios2 = zeros(NumGVCAct,NumGVCAct,NumProducts);

NumGVCAct = size(GVCAct,1);
OpporValScenarios2 = zeros(NumGVCAct,NumGVCAct,1); %1) Oppor Value (per scenario)
Densities = zeros(size(Products,1),1);

ScenarioRCA = zeros(size(BaseRCASpace));

for Act1 = 1:NumGVCAct

  for Act2 = 1:NumGVCAct

    ScenarioRCA = GVCRCAScenarios2(Act1,Act2,:); %+ transpose(BaseRCASpace);
```

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```
        for i=1:size(Products,1) % Run through all potential products

            if ScenarioRCA(i) <= 1 % If opportunity not exploited yet

                DensityNumerator = 0;

                for j=1:size(Products,1) %Run through all columns of the proximity matrix

                    if ScenarioRCA(j) > 1 % If you are already competitive; calculate Density from competitive to opportunity

                        if i ~= j % Make sure product is not not itself

                            DensityNumerator = DensityNumerator + Prox(i,j);

                        end

                    end
                end

                Densities(i) = DensityNumerator / (ProxSums(i) - 1);

                %if RCA(i,2) <= 1 % If opportunity not exploited yet, add to unexploited column

                OpporValScenarios2(Act1,Act2) = OpporValScenarios2(Act1,Act2) + Densities(i) * ProductCompInd(i);

            end

        end

    end

end

OpporVal2Timed = toc(OpporVal2Time)

end

function OpporValScenarios3 = CalcOppValScenarios3(Products,Prox,ProductCompInd,GVCRCAScenarios3,GVCAct,BaseRCASpace,ProxSums)

%GVCRCAScenarios2 = zeros(NumGVCAct,NumGVCAct,NumProducts);

OpporVal3Time = tic;

NumGVCAct = size(GVCAct,1);
OpporValScenarios3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,1); %1) Oppor Value (per scenario)
Densities = zeros(size(Products,1),1);
```

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```
ScenarioRCA = zeros(size(BaseRCASpace));

for Act1 = 1:NumGVCAct

   for Act2 = 1:NumGVCAct

      for Act3 = 1:NumGVCAct

         ScenarioRCA = GVCRCAScenarios3(Act1,Act2,Act3,:); %+ transpose(BaseRCASpace);

         for i=1:size(Products,1) % Run through all potential products

            if ScenarioRCA(i) <= 1 % If opportunity not exploited yet

               DensityNumerator = 0;

               for j=1:size(Products,1) %Run through all columns of the proximity matrix

                  if ScenarioRCA(j) > 1 % If you are already competitive; calculate Density from competitive to opportunity

                     if i ~= j % Make sure product is not not itself

                        DensityNumerator = DensityNumerator + Prox(i,j);

                     end

                  end
               end

               Densities(i) = DensityNumerator / (ProxSums(i) - 1);

               %if RCA(i,2) <= 1 % If opportunity not exploited yet, add to unexploited column

               OpporValScenarios3(Act1,Act2,Act3) = OpporValScenarios3(Act1,Act2,Act3) + Densities(i) * ProductCompInd(i);

            end

         end

      end

   end

   Act1

   Of = NumGVCAct

end
```

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```
OpporVal3Timed = toc(OpporVal3Time)

end

function [BestFrom1Comp BestFrom1Oppor BestComplexityContr BestOpporGain] = CalcBestFrom1(Round1Metrics,ScenariosDistances,BaseLineMetrics)

%Round1Metrics = [CompContr OpporGainScenarios1 DistReq1];

BestComplexityContr = zeros(size(ScenariosDistances,1),1);
BestOpporGain = zeros(size(ScenariosDistances,1),1);

BestFrom1Comp = zeros(size(ScenariosDistances,1),5); % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) BextComplexity Contr; 5) OpporGain; 6) Distance
BestFrom1Oppor = zeros(size(ScenariosDistances,1),5); % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) Complexity Contr; 5) BestOpporGain; 6) Distance

BestFrom1Comp(:,4) = BaseLineMetrics(2);

for i = 1:size(ScenariosDistances,1) %Repeat for all scenarios

   for j = 1:size(Round1Metrics,1) %Repeat for all activities

      if Round1Metrics(j,3) < ScenariosDistances(i) %Test distance requirement

         if Round1Metrics(j,1) > BestComplexityContr(i) % Test if best complexity for scenario

            BestComplexityContr(i) = Round1Metrics(j,1);

            BestFrom1Comp(i,1) = j; %Capture activity
            BestFrom1Comp(i,2) = 0;
            BestFrom1Comp(i,3) = 0;
            BestFrom1Comp(i,4) = Round1Metrics(j,1); %Capture complexity contr
            BestFrom1Comp(i,5) = Round1Metrics(j,2); %Capture Oppor gain
            BestFrom1Comp(i,6) = Round1Metrics(j,3); %Capture Distance

         end

         if Round1Metrics(j,2) > BestOpporGain(i); % Test if best Oppor Gain for Scenario

            BestOpporGain(i) = Round1Metrics(j,2);

            BestFrom1Oppor(i,1) = j; %Capture activity
            BestFrom1Oppor(i,2) = 0;
            BestFrom1Oppor(i,3) = 0;
            BestFrom1Oppor(i,4) = Round1Metrics(j,1); %Capture complexity contr
            BestFrom1Oppor(i,5) = Round1Metrics(j,2); %Capture Oppor gain
            BestFrom1Oppor(i,6) = Round1Metrics(j,3); %Capture Distance

         end

      end
```

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```
    end

end

end

function [BestFrom2Comp BestFrom2Oppor BestComplexityContr BestOpporGain] = CalcBestFrom2(Comp2,DistReq2,OpporGainScenarios2,ScenariosDistances,BestFrom1Comp,BestFrom1Oppor,BestComplexityContr,BestOpporGain)

%BestComplexityContr = zeros(size(ScenariosDistances,1),1);
%BestOpporGain = zeros(size(ScenariosDistances,1),1);

BestFrom2Comp = BestFrom1Comp; % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) BextComplexity Contr; 5) OpporGain; 6) Distance
BestFrom2Oppor = BestFrom1Oppor; % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) Complexity Contr; 5) BestOpporGain; 6) Distance

for i = 1:size(ScenariosDistances,1) %Repeat for all scenarios

    for j = 1:size(DistReq2,1) %Repeat for all activities

        for k = 1:size(DistReq2,1) %Repeat for all activities

            if DistReq2(j,k) < ScenariosDistances(i) %Test distance requirement

                if Comp2(j,k) > BestComplexityContr(i) % Test if best complexity for scenario

                    BestComplexityContr(i) = Comp2(j,k);

                    BestFrom2Comp(i,1) = j; %Capture activity 1
                    BestFrom2Comp(i,2) = k; %Capture activity 2
                    BestFrom2Comp(i,3) = 0;
                    BestFrom2Comp(i,4) = Comp2(j,k); %Capture complexity contr
                    BestFrom2Comp(i,5) = OpporGainScenarios2(j,k); %Capture Oppor gain
                    BestFrom2Comp(i,6) = DistReq2(j,k); %Capture Distance

                end

                if OpporGainScenarios2(j,k) > BestOpporGain(i); % Test if best Oppor Gain for Scenario

                    BestOpporGain(i) = OpporGainScenarios2(j,k);

                    BestFrom2Oppor(i,1) = j; %Capture activity 1
                    BestFrom2Oppor(i,2) = k; %Capture activity 2
                    BestFrom2Oppor(i,3) = 0;
                    BestFrom2Oppor(i,4) = Comp2(j,k); %Capture complexity contr
                    BestFrom2Oppor(i,5) = OpporGainScenarios2(j,k); %Capture Oppor gain
                    BestFrom2Oppor(i,6) = DistReq2(j,k); %Capture Distance

                end
```

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```
            end

        end

    end

end

end

function [BestFrom3Comp BestFrom3Oppor BestComplexityContr BestOpporGain] =
CalcBestFrom3(Comp3,DistReq3,OpporGainScenarios3,ScenariosDistances,BestFrom2Comp,Best
From2Oppor,BestComplexityContr,BestOpporGain)


%BestComplexityContr = zeros(size(ScenariosDistances,1),1);
%BestOpporGain = zeros(size(ScenariosDistances,1),1);

BestFrom3Comp = BestFrom2Comp; % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) BextComplexity
Contr; 5) OpporGain; 6) Distance
BestFrom3Oppor = BestFrom2Oppor; % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) Complexity
Contr; 5) BestOpporGain; 6) Distance

for i = 1:size(ScenariosDistances,1) %Repeat for all scenarios

    for j = 1:size(DistReq3,1) %Repeat for all activities

        for k = 1:size(DistReq3,1) %Repeat for all activities

            for m = 1:size(DistReq3,1) %Repeat for all activities

                if DistReq3(j,k,m) < ScenariosDistances(i) %Test distance requirement

                    if Comp3(j,k,m) > BestComplexityContr(i) % Test if best complexity for scenario

                        BestComplexityContr(i) = Comp3(j,k,m);

                        BestFrom3Comp(i,1) = j; %Capture activity 1
                        BestFrom3Comp(i,2) = k; %Capture activity 2
                        BestFrom3Comp(i,3) = m;
                        BestFrom3Comp(i,4) = Comp3(j,k,m); %Capture complexity contr
                        BestFrom3Comp(i,5) = OpporGainScenarios3(j,k,m); %Capture Oppor gain
                        BestFrom3Comp(i,6) = DistReq3(j,k,m); %Capture Distance

                    end

                    if OpporGainScenarios3(j,k,m) > BestOpporGain(i); % Test if best Oppor Gain for
Scenario

                        BestOpporGain(i) = OpporGainScenarios3(j,k,m);
```

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```
                    BestFrom3Oppor(i,1) = j; %Capture activity 1
                    BestFrom3Oppor(i,2) = k; %Capture activity 2
                    BestFrom3Oppor(i,3) = m;
                    BestFrom3Oppor(i,4) = Comp3(j,k,m); %Capture complexity contr
                    BestFrom3Oppor(i,5) = OpporGainScenarios3(j,k,m); %Capture Oppor gain
                    BestFrom3Oppor(i,6) = DistReq3(j,k,m); %Capture Distance

                end

            end

        end

    end

end

end

end

function [MetricsForWinnersComp MetricsForWinnersOppor] = CalcMetricsOfWinner(BestFrom3Comp,BestFrom3Oppor,GVCRCAScenarios3,GVCRCAScenarios2,GVCRCAScenarios1,Prox,ProxSums,Products,GVCFull)

%BestFrom3Comp = BestFrom2Comp; % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) BextComplexity Contr; 5) OpporGain; 6) Distance
%BestFrom3Oppor = BestFrom2Oppor; % 1) Activity1; 2) Activity 2; 3) Activity 3; 4) Complexity Contr; 5) BestOpporGain; 6) Distance

%GVCFullRCAScenarios3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,NumInGVCFull);
%GVCRCAScenarios3 = zeros(NumGVCAct,NumGVCAct,NumGVCAct,NumProducts);

%GVCFullRCAScenarios2 = zeros(NumGVCAct,NumGVCAct,NumInGVCFull);
%GVCRCAScenarios2 = zeros(NumGVCAct,NumGVCAct,NumProducts);

%GVCFullRCAScenarios1 = zeros(NumGVCAct,NumInGVCFull);
%GVCRCAScenarios1 = zeros(NumGVCAct,NumProducts);

NumScenarios = size(BestFrom3Comp,1);
NumProducts = size(GVCRCAScenarios1,2);

RCAOppor1 = zeros(NumProducts);
RCAOppor2 = zeros(NumProducts);
RCAOppor3 = zeros(NumProducts);
RCAComp1 = zeros(NumProducts);
RCAComp2 = zeros(NumProducts);
RCAComp3 = zeros(NumProducts);


MetricsForWinnersComp = zeros(NumScenarios,2);  % 1) Average distance to products in the value chain with RCA < 1; 2) Average distance to products in the products space with RCA <1
```

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```
MetricsForWinnersOppor = zeros(NumScenarios,2); % 1) Average distance to products in the value chain with RCA < 1; 2) Average distance to products in the products space with RCA <1

for i = 1:NumScenarios % Run through all winners

  %% Part for Best From Comp

  CompA1 = BestFrom3Comp(i,1);
  CompA2 = BestFrom3Comp(i,2);
  CompA3 = BestFrom3Comp(i,3);

  if CompA1 ~= 0 %if true, there are 0 activities that meet the specificiation.

    if CompA2 == 0 %If true, there is only 1 activity

      for j = 1:NumProducts

        RCAComp1(j) = GVCRCAScenarios1(CompA1,j);

      end

      MetricsForWinnersComp(i,1) = CalcDistToVC(RCAComp1,GVCFull,Prox,ProxSums,Products);
      MetricsForWinnersComp(i,2) = CalcDistToPS(RCAComp1,Prox,ProxSums,Products);

    else % If not true, then there are either 2 or 3 activities in answer

      if CompA3 == 0 %If true, then there are 2 activities in answer

        for j = 1:NumProducts

          RCAComp2(j) = GVCRCAScenarios2(CompA1,CompA2,j);

        end

        MetricsForWinnersComp(i,1) = CalcDistToVC(RCAComp2,GVCFull,Prox,ProxSums,Products);
        MetricsForWinnersComp(i,2) = CalcDistToPS(RCAComp2,Prox,ProxSums,Products);

      else %If not true, then there are 3 activities in answer

        for j = 1:NumProducts

          RCAComp3(j) = GVCRCAScenarios3(CompA1,CompA2,CompA3,j);

        end

        MetricsForWinnersComp(i,1) = CalcDistToVC(RCAComp3,GVCFull,Prox,ProxSums,Products);
        MetricsForWinnersComp(i,2) = CalcDistToPS(RCAComp3,Prox,ProxSums,Products);

      end
```

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```
        end

    end

    %% Part for Best From Oppor

    OpporA1 = BestFrom3Oppor(i,1);
    OpporA2 = BestFrom3Oppor(i,2);
    OpporA3 = BestFrom3Oppor(i,3);

    if OpporA1 ~= 0 %If  true, there are 0 activities

        if OpporA2 == 0 %If  true, there is only 1 activity

            for j = 1:NumProducts

                RCAOppor1(j) = GVCRCAScenarios1(OpporA1,j);

            end

            MetricsForWinnersOppor(i,1) = CalcDistToVC(RCAOppor1,GVCFull,Prox,ProxSums,Products);
            MetricsForWinnersOppor(i,2) = CalcDistToPS(RCAOppor1,Prox,ProxSums,Products);


        else % If not true, then there are either 2 or 3 activities in answer

            if OpporA3 == 0 %If true, then there are 2 activities in answer

                for j = 1:NumProducts

                    RCAOppor2(j) = GVCRCAScenarios2(OpporA1,OpporA2,j);

                end

                MetricsForWinnersOppor(i,1) = CalcDistToVC(RCAOppor2,GVCFull,Prox,ProxSums,Products);
                MetricsForWinnersOppor(i,2) = CalcDistToPS(RCAOppor2,Prox,ProxSums,Products);

            else %If not true, then there are 3 activities in answer

                for j = 1:NumProducts

                    RCAOppor3(j) = GVCRCAScenarios3(OpporA1,OpporA2,OpporA3,j);

                end

                MetricsForWinnersOppor(i,1) = CalcDistToVC(RCAOppor3,GVCFull,Prox,ProxSums,Products);
                MetricsForWinnersOppor(i,2) = CalcDistToPS(RCAOppor3,Prox,ProxSums,Products);
```

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```
         end

      end

   end

end

end

function AvgDistToVCNotAqYet = CalcDistToVC(ProdRCA,GVCFull,Prox,ProxSums,Products)

%GVCFull 1) Tier#; 2) GVC Activity#; 3) HS Code; 4 Complexity; 5) Density; 6) RCA (7) Complexity if opp; 8) Distance if Opportunity; 9) OpporGain if Opportunity; 10)RCA if Opp; 11) SA Export of Activity; 12) World Export of activity; 13) SA export if oppor; 14) World export if opp; 15) ProdPosition

%% Calculate Distance To Products In The Product Space Not yet Acquired

NumberNotAcquired = 0;
Distance = zeros(size(Products,1),1);
DistanceNumerator = zeros(size(Products,1),1);

for i=1:size(GVCFull,1) % Run through all potential products

   if ProdRCA(GVCFull(i,15)) <= 1 % If opportunity not exploited yet, distance to it can be calculated.

      NumberNotAcquired = NumberNotAcquired + 1;

      for j=1:size(Products,1) %Run through all columns of the proximity matrix

         if ProdRCA(j) < 1 % If you are not yet competitive; add to distance to opportunity

            if i ~= j % Make sure product is not not itself

               DistanceNumerator(i) = DistanceNumerator(i) + Prox(GVCFull(i,15),j);

            end

         end
      end

      Distance(i) = DistanceNumerator(i) / (ProxSums(GVCFull(i,15)) - 1);

   end

end

SumDistances = sum(Distance);
AvgDistToVCNotAqYet = SumDistances / NumberNotAcquired;
```

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```
end

function AvgDistToPSNotAqYet = CalcDistToPS(ProdRCA,Prox,ProxSums,Products)

%ProdRCA
%GVCFullRCA

%% Calculate Distance To Products In The Product Space Not yet Acquired

NumberNotAcquired = 0;
Distance = zeros(size(Products,1),1);
DistanceNumerator = zeros(size(Products,1),1);

for i=1:size(Products,1) % Run through all potential products

    if ProdRCA(i) <= 1 % If opportunity not exploited yet, distance to it can be calculated.

        NumberNotAcquired = NumberNotAcquired + 1;

        for j=1:size(Products,1) %Run through all columns of the proximity matrix

            if ProdRCA(j) < 1 % If you are not yet competitive; add to distance to opportunity

                if i ~= j % Make sure product is not not itself

                    DistanceNumerator(i) = DistanceNumerator(i) + Prox(i,j);

                end

            end
        end

        Distance(i) = DistanceNumerator(i) / (ProxSums(i) - 1);

    end

end

SumDistances = sum(Distance);
AvgDistToPSNotAqYet = SumDistances / NumberNotAcquired;


end
```

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Appendix G

SITC Model results

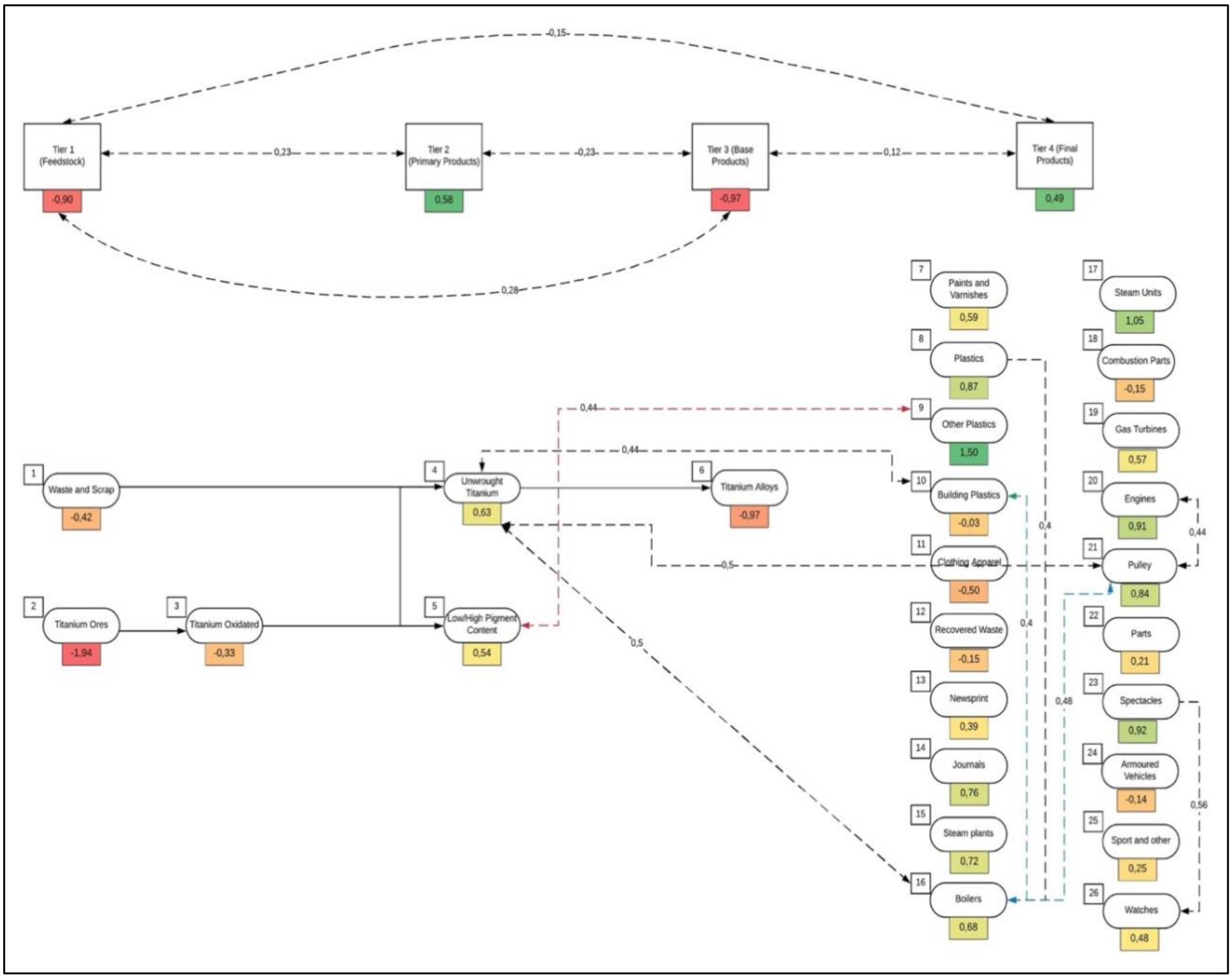

Figure G.1: SITC 4-digit aggregated tier and category complexity and proximity values (proximity value <0,4)

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Table G.1: SITC Case specific (South African) metrics aggregated at tier level

Tier#	Average RCA	Average complexity for product with RCA < 1	Average distance for products with RCA < 1	Average opportunity gain for products with RCA < 1
1	24,67	NaN	NaN	NaN
2	1,38	0,58	0,73	0,28
3	30,71	NaN	NaN	NaN
4	0,65	0,60	0,75	0,26

Table G.2: SITC metrics for South Africa at the product category level

Product Category #	Average RCA	Average Complexity of the products within the VC if all products within the category have a RCA > 1	Opportunity gain if all products in category have RCA > 1	Sum of distances to products in category
Baseline		-0,26		
Tier 1				
1	3,28	-0,26	N/A	N/A
2	46,05	-0,26	N/A	N/A
3	2,30	-0,26	N/A	N/A
Tier 2				
4	0,41	-0,19	0,09	0,73
5	0,50	-0,20	0,15	0,73

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6	30,71	-0,26	N/A	N/A
7	0,65	-0,11	0,32	2,20
Tier 3				
8	0,71	-0,10	0,20	1,50
Tier 4				
9	0,52	-0,13	0,14	0,76
10	0,88	-0,27	0,11	0,69
11	0,24	-0,28	0,09	0,80
12	0,19	-0,25	0,08	0,70
13	1,13	-0,12	0,22	2,21
14	0,48	-0,01	0,48	2,98
15	0,54	-0,11	0,22	1,56
16	0,14	-0,19	0,10	0,73
17	0,18	-0,07	0,34	1,55
18	2,17	-0,17	0,09	0,74
19	0,11	-0,14	0,31	1,49
20	0,48	-0,17	0,07	0,74
21	0,52	-0,18	0,08	0,74
22	0,49	-0,22	0,12	0,72
23	0,15	-0,17	0,16	0,80
24	1,80	-0,26	N/A	N/A
25	0,10	-0,19	0,22	1,50
26	0,09	-0,20	0,10	0,78

Table G.3: SITC Model results for complexity maximising case

Distance constraint	Distance used	Product Category 1	Product Category 2	Product Category 3	Average Complexity of the products within the VC with a RCA > 1	Total opportunity gain (considering entire product space)	Average distance to products in the value chain with RCA < 1	Average distance to products in the product space with RCA < 1
Initial Metrics					-0,26	N/A	0,75	0,75
0	0	0	0	0	-0,26	N/A	N/A	N/A
0	0	0	0	0	-0,26	N/A	N/A	N/A
0	0	0	0	0	-0,26	N/A	N/A	N/A
0	0	0	0	0	-0,26	N/A	N/A	N/A
3	2,29	9	18	23	0,02	0,39	0,75	0,74

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3	2,30	9	17	0	0,03	0,48	0,75	0,74
4	3,04	9	18	17	0,09	0,55	0,74	0,74
4	3,04	9	18	17	0,09	0,55	0,74	0,74
4	3,79	8	9	17	0,13	0,65	0,74	0,74
4	3,79	8	9	17	0,13	0,65	0,74	0,74
5	4,47	9	14	18	0,13	0,68	0,74	0,74
5	4,47	9	14	18	0,13	0,68	0,74	0,74
6	5,27	9	14	17	0,18	0,91	0,74	0,74
6	5,27	9	14	17	0,18	0,91	0,74	0,74
7	6,00	8	14	17	0,19	0,95	0,74	0,73

Table G.4: SITC Model results for opportunity gain maximising case

Distance constraint	Distance used	Product Category 1	Product Category 2	Product Category 3	Average Complexity of the products within the VC with a RCA > 1	Total opportunity gain (considering entire product space)	Average distance to products in the value chain with RCA < 1	Average distance to products in the product space with RCA < 1
Initial Metrics					-0,26	N/A	0,75	0,75
1	0,69	10	0	0	-0,27	0,11	0,75	0,74
1	0,80	23	0	0	-0,17	0,16	0,75	0,74
2	1,49	19	0	0	-0,14	0,31	0,75	0,74
2	1,55	17	0	0	-0,07	0,34	0,75	0,74
3	2,27	5	17	0	-0,03	0,48	0,75	0,74
3	2,34	17	23	0	-0,01	0,50	0,74	0,74
4	3,07	5	17	23	0,03	0,64	0,74	0,74
4	3,07	5	17	23	0,03	0,64	0,74	0,74
4	3,83	17	19	23	0,06	0,79	0,74	0,74
4	3,83	17	19	23	0,06	0,79	0,74	0,74
5	4,53	17	19	25	0,03	0,85	0,74	0,74
5	4,53	17	19	25	0,03	0,85	0,74	0,74
6	5,31	14	17	23	0,15	0,94	0,74	0,74
6	5,31	14	17	23	0,15	0,94	0,74	0,74
6	6,00	14	17	19	0,16	1,07	0,74	0,73

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Appendix H

South African trade markets for selected categories

Table H.1: Top collaborators with South Africa for HS 840681

Year	Origin	Collaborator	HS07	Export Value to Collaborator	Import Value from collaborator	% Share of SA Export Market	% Share of SA Import market
2014	zaf	cog	840681	$ 3 146,00		0,38	
2014	zaf	gha	840681	$ 1 650,00		0,20	
2014	zaf	moz	840681	$ 39 995,00		4,79	
2014	zaf	mwi	840681	$ 4 248,00		0,51	
2014	zaf	tun	840681		$ 83 625,00		0,04
2014	zaf	tza	840681	$ 68 038,00		8,15	
2014	zaf	zwe	840681	$ 5 038,00		0,60	
2014	zaf	chn	840681		$ 8 131 970,00		3,47
2014	zaf	ind	840681		$ 1 053 376,00		0,45
2014	zaf	isr	840681		$ 447 125,00		0,19
2014	zaf	kor	840681		$ 1 806 641,00		0,77
2014	zaf	mys	840681		$ 37 325,00		0,02
2014	zaf	tha	840681		$ 14 400 039,00		6,14
2014	zaf	tur	840681		$ 1 267 067,00		0,54
2014	zaf	xxb	840681		$ 359 843,00		0,15
2014	zaf	aut	840681		$ 14 272 260,00		6,09
2014	zaf	blx	840681		$ 2 809 007,10		1,20
2014	zaf	che	840681		$ 895 828,00		0,38
2014	zaf	cze	840681		$ 197 318,00		0,08
2014	zaf	deu	840681	$ 585 126,00	$ 145 693 874,00	70,09	62,13
2014	zaf	esp	840681		$ 41 857,00		0,02
2014	zaf	fin	840681		$ 2 081 644,00		0,89
2014	zaf	fra	840681	$ 24 912,00	$ 15 570 831,94	2,98	6,64
2014	zaf	gbr	840681		$ 1 195 838,32		0,51
2014	zaf	hun	840681		$ 1 363 300,00		0,58
2014	zaf	irl	840681		$ 55 063,00		0,02

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2014	zaf	ita	840681		$ 4 873 363,32		2,08
2014	zaf	nld	840681		$ 4 074 584,00		1,74
2014	zaf	pol	840681	$ 102 711,00	$ 2 563 978,00	12,30	1,09
2014	zaf	swe	840681		$ 1 653 022,00		0,70
2014	zaf	usa	840681		$ 8 140 622,00		3,47
2014	zaf	bra	840681		$ 1 426 272,00		0,61
Total				$ 834 864,00	$ 234 495 673,68	100	100

Table H.2: Top collaborators with South Africa for HS 840682

Year	Origin	Collaborator	HS07	Export Value to Collaborator	Import Value from collaborator	% Share of SA Export Market	% Share of SA Import market
2014	zaf	ago	840682	$ 2 263,00		0,59	
2014	zaf	civ	840682	$ 10 972,00		2,87	
2014	zaf	mdg	840682	$ 1 801,00		0,47	
2014	zaf	moz	840682	$ 76 490,24		20,03	
2014	zaf	nga	840682	$ 110 242,00		28,86	
2014	zaf	chn	840682		$ 10 119,00		0,14
2014	zaf	hkg	840682		$ 3 572,00		0,05
2014	zaf	ind	840682	$ 180 165,00	$ 165 811,00	47,17	2,31
2014	zaf	jpn	840682		$ 13 017,00		0,18
2014	zaf	kor	840682		$ 17 622,00		0,25
2014	zaf	aut	840682		$ 224 624,00		3,13
2014	zaf	che	840682		$ 33 808,00		0,47
2014	zaf	deu	840682		$ 2 234 337,49		31,16
2014	zaf	fra	840682		$ 41 161,00		0,57
2014	zaf	gbr	840682		$ 796 005,00		11,10
2014	zaf	ita	840682		$ 28 379,00		0,40
2014	zaf	nld	840682		$ 3 485 979,00		48,62
2014	zaf	pol	840682		$ 2 038,00		0,03
2014	zaf	rou	840682		$ 28 898,00		0,40
2014	zaf	usa	840682		$ 85 025,52		1,19
Total				$ 381 933,24	$ 7 170 396,01	100	100

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Appendix I

Steam turbine industry and market report

I.1. Market-related dynamic forces and importance ratings

Table I.1: Market dynamic analysis through drivers, opportunities, restraints and challenges

Dynamic force	Forces	Description	Importance
Drivers	Increasing electricity consumption and consequent investments in generation capacity	The demand for power consumption is increasing on a yearly basis due to growing industrialisation and use of electrical appliances	High
		Increasing electricity consumption and consequent investments on generation capacity are the drivers of the steam turbine market	
	Rising thermal power capacity additions	Emerging economies especially in the Asia-Pacific region are expected to be the largest players contributing to global power generation additions	High
		The increase in generation capacity is expected to be primarily achieved through the additions of coal-based thermal power plants. This will serve as a primary source for electricity generation	
	Increase in combined cycle and co-generation operations	Adding steam turbines to utilise the wasted heat and steam will increase the overall efficiency of these plants whilst adding capacity to them	High
		Growing adoption of combined cycle and co-generation operations increases the demand for steam turbines	
Restraint	Regulatory and policy restriction on fossil-fuel fired power plant	Government is enforcing regulations that hamper new fossil-fuel fired power generation projects	Moderate
		Large thermal power plants encounter regulatory and policy restrictions that are currently hindering growth	

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	Slowdown in construction of nuclear power plants	Perception in the nuclear power industry is contaminated with viewpoints considering it as fraught with costs, sustainability and safety costs	Moderate
		Nuclear projects are filled with delays in work and cost	
Opportunity	Replacement/ Upgrades of aged power generation infrastructure	Tougher regulatory requirements for building new fossil-fuel fired power plants	Moderate
		Replacing old equipment enables power producers to reduce overall operational costs, better power generating capacity whilst optimising water usage	
Challenge	Boiler efficiency and steam quality	Steam turbines depend on high-quality steam to function optimally and avoid mechanical failures	Moderate to low
		Inefficient boilers will lead to higher fuel requirements increasing the generation and overall costs	

I.2. Porters 5 forces

Once the key drivers have been established, the competitive structure of the market must also be established. This will allow the assessment of where South Africa will have key leverage areas with inherited advantages and where South Africa should focus on enhancing locational factors.

Table I.2: Porters 5 forces to market entry

Force	Rating	Description
Threat of new entrant	Low	High-capital requirement is a large barrier for new entrants, additional expenses linked to testing, distributing and maintenance and service facilities. The design and manufacturing of components such as blades, nozzles and other critical components needs to be done with almost zero tolerance for errors increasing the costs. The sourcing of raw materials for components is difficult and involves high costs, which is favourable for South Africa, but increases capital requirements. New players will require a large capital investment to compete with existing players.
Threat of substitute	Moderate to high	Competition from other generating technologies, particularly renewables such as wind turbines, solar photovoltaic power systems and hydropower turbines. Due to similar capabilities South

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		Africa can start producing those as well. Climate change and focus on carbon emissions are threatening its dominance.
Bargaining power of supplier	Low to moderate	Dependence on regulatory policy in the buyer's market, due to the market being heavily regulated by the government, buyers have little leverage to bargain with. They can be affected by sudden market changes based on policy changes.
Bargaining power of buyers	Moderate to high	Concentration of buyers in the market is higher than those of the sellers. Buyers are either state-owned utilities or large EPC contractors hired by utilities. Making them concentrated and allowing to be affected by regulations such as local sourcing. Sellers might find themselves locked out of a market due to regulatory or political reasons.
Intensity of rivalry	High	High degree of competition, competitors are relatively equal in terms of financial and technological dominance. Companies are using aggressive moves such as region-specific and segment-specific alliances, joint ventures and acquisitions to strengthen their businesses.
		Most new thermal power orders coming from limited markets, as most are being built in Asia-Pacific and emerging economies. Thus, suppliers are competing for a share of the same pie. International manufacturers have entered into alliances with local turbine players in large markets such as China and India.

I.3. Industry competitive landscape

The steam turbine market is currently dominated by key players such as Alstom SA (France), Siemens AG (Germany), Toshiba Corporation (Japan), General Electric Company (U.S.) and Mitsubishi Hitachi Power Systems (Japan). These top players accounted for about 51% of the market share in 2014. They primarily rely on contracts and agreements as one of their key strategies to gain market share with expansion having an effect as a lucrative growth strategy. Mergers and acquisitions played a crucial role for companies such as MAN Diesel and Turbo SE (Germany) and Toshiba Corporation (Japan). There are new technological innovations related to double extraction steam turbine technology, which boosted companies such as Donfag Electric Corporation Limited (China) and Harbin Electric International Limited (China).

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Table I.3: Key players' strategies for market growth and revenue growth

Company name	**Organic growth strategies**		**Inorganic growth strategies**	
	New product launches	*Expansion*	*Merger and acquisitions*	*Contracts agreements and partnerships*
Alstom SA	Longest turbine blade for nuclear steam turbines, reducing exhaust losses			Signed two contracts with Burmeister and Wain Scandinavian for geared reaction steam turbines to be used
Siemens AG				Received contract from Lavalin Construction Inc for supplying gas turbines and other turbines.
Toshiba Corporation			Merged three of its US businesses	Received order for two sets of 175MW steam turbines and generators
General Electric Company			Acquired the power systems business division of Alstom SA.	Received a contract from GS Power for supplying gas turbines, clutched steam turbines to enhance efficiency of combined cycle power plant
Mitsubishi Hitachi Power Systems		Reorganised manufacturing facilities in Japan to achieve higher productivity and to strengthen competitiveness.		Received an order to supply gas turbines, steam turbines etc. for co-generation project

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Appendix J

Questionnaire and evaluation for market- and location-related factors

J.1. Questionnaire sent out

1. Does the company classify as a multinational company? If so, where are the head offices based and in how many countries does the company currently operate?

___

2. How would you define your target market and market segment?

___

3. Give a rating out of 10, 10 being the highest, indicating the importance of each factor for attaining market share within this industry and how much the country of operation contributes to achieving the required levels of satisfaction for each factor?

Factor	Factor Importance	Country Contribution
Cost of product		
Quality of product		
Responsiveness to market change		
Lead time		

4. Where are your key markets located? What is the distance and means of transport for getting the products to the markets?

___

5. What role does each of the following play in affecting competitiveness in this industry and what is your country's performance on these for your target market?

Moderators	Role	Country Performance
Trade barriers		
Transportation costs		
Interaction costs		
Political factors between countries		

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6. On a scale of 1-10 rate the importance of the following factors relevant to the activity or industry the company is involved in; these factors tend to affect the impact of location determinants on the **performance potential** at the location. Also provide a rating of how well the country is currently performing in providing the necessary assistance to achieve success in these factors:

Moderating factor	Illustrative impact	Importance	Country Performance
Complexity of production processes	Complexity determines skills and experience required to perform the activities. Is local skill important?		
Dynamism of the product market environment	Importance of knowledgeable supporting firms, is there other firms that can provide supporting functions?		
Spillover importance of knowledge employed	Knowledge not easily spilled over beyond cluster. Is it important to be close to competitors and supporting industries to acquire knowledge?		
Economies of scale	Cost factors play a bigger role, as production takes place in fewer places and differences are marginalised.		

7. Provide a rating between 1-10 for which of the **following performance dimensions are considered the most important in the industry** as well as a rating on the country's performance:

Manufacturing		Rating	Country Performance
Cost	Labour costs and productivity		
	Exchange rates		
	Incentives, grants and subsidies		
	Taxes		
	Trade protection		
	Investment barriers		
	Cost of capital		
	Cost of industrial land		
	Availability and cost of utilities		
	Competition in factor markets		
	Managerial skills available		
	Transport costs		
	Infrastructure		
	Nearness and quality of material inputs and suppliers		
	Natural hazards based on geography		
	Capacity changing and switching costs		
	Contracting environment		
	Skills availability		
	Demand distance		
	Government policy and regulation		
Lead time	Infrastructure		

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	Distance		
Flexibility	Nearness and quality of material inputs and suppliers		
	Nearness and quality of supporting services		
	Institutions and trusts		
	Capacity changing and switching costs		
	Contracting environment		
	Skills availability		
	Demand distance		
Reliability	Nearness and quality of material inputs and suppliers		
	Infrastructure		
	Natural hazards based on geography		
	Institutions and trusts		
Responsiveness	Nearness and quality of material inputs and suppliers		
	Nearness and quality of supporting services		
	Institutions and trusts		
	Capacity changing and switching costs		
	Contracting environment		
	Demand distance		
Quality	Nearness and quality of supporting services		
	Skills availability		
Sustainability	Nearness and quality of material inputs and suppliers		
	Demand distance		
	Government policy and regulation		
Research			
Responsiveness to leading customers	Skills availability		
	Quality and scale of science and technology		
	Cultural collectivism, power distance and risk appetite		
Ability to improve the state of the art	Skills availability		
	Quality and scale of science and technology		
	Availability and cost of knowledge assets and technology		
	Location of global centres of excellence		
	Nearness and quality of supporting services		
	Distribution of welfare		
	Size, number and location of competitors		
	IP regulation		
Protection of IP	Size, number and location of competitors		
	IP regulation		
Development			
	Skills availability		

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Responsiveness to local taste	Quality and scale of science and technology		
	Availability and cost of knowledge assets and technology		
	Risk appetite		
	Nearness and quality of supporting services		
	Proximity to manufacturing		
Protection of IP	Size, numbers and location of competitors		
	IP regulation		

J.2. Case study with market report

In Table J.1 below, the market dynamics are discussed. These factors are rated based on information from a MarketsandMarkets™ report on the steam turbine industry. MarketsandMarkets™ used both primary and secondary data sources to gather the data. Primary sources consisted of several industry experts from both steam turbine and power generation industries. During the interviews qualitative and quantitative information and future prospects were assessed. Secondary sources contained publicly available information such as press releases, investment reports and presentations.

Table J.1: Rating of location-centric factors

Steam Turbine			
LT	RT	LB	RB
Winning market share			
Cost of product	Quality of product	Lead time	Responsiveness to market change (Still important but on scale against quality not as important)
	Interaction, Transportation costs	Political factors between countries	
From South Africa's perspective their capabilities to gain market share are evenly distributed with opportunities from which they can benefit and other challenges that are difficult to overcome. The quality requirements of steam boilers remain of the highest standards, with the market always searching for more efficient boilers and higher-quality steam driving up the required quality of the products. Currently, South Africa has limited research and infrastructure in the steam turbine manufacturing industry and cannot contribute towards enhancing quality, but with the clear guidance and support of the DST this can be changed, as South Africa can invest in the necessary infrastructure requirements and world-class research facilities. The cost of the products is likely to remain high as industry standards are high. The limited interference that South Africa can provide, rests in supplying the expensive parts such as the blades at a more affordable price through providing affordable raw material prices to local manufacturers. Still important, but not as critical,			

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is the lead time and responsiveness to market change, as the request for new steam turbine plants requires thorough planning. South Africa has limited influence on lead time, as the distance to markets remains constant, but can intervene through expanding its footprint in the supply chain and starting to manufacture most parts locally, which in turn allows for a quick response to market changes. Unfortunately, from a developing country perspective, South Africa remains exposed to world politics and does not have a strong position to enforce favourable political factors. This might also be beneficial, as industry leaders might be more willing to enter into partnership with the local industry. The last factor is support in infrastructure, as this could drive down costs and allow higher market interaction.			
Location ability to support activity			
Complexity of production process	Dynamism of product market environment	Economies of scale	
Spillover importance of knowledge employed.			
The complexity of the steam turbine market is a given factor, which South Africa cannot control or alter, but an aspect which the country has to make sure of is that it meets the industry standards. Just because it cannot control the complexity of production, does not imply it is a barrier. Although it is a complex production process, with the correct investments, South Africa should be able to meet the complexity demands, as the industry requires capabilities close to South Africa's current capabilities. Through proper research programmes, collaborations and merger and acquisitions, South Africa should be able to acquire the critical knowledge to keep up with the industry. South Africa could promote the local manufacture of various parts or processes involved in the supply chain, allowing the local industry to keep up with the dynamics involved in the industry, especially upgrades and replacement of parts where companies seek to shift towards co-generations or upgrading of parts for higher efficiency. As with any industry, higher economies of scale will be more beneficial for South Africa, but steam turbines being a niche market, implies that economies of scale are not as important, and realistically not achievable.			
Industry Performance dimensions – Manufacturing (Cost)			
Exchange rate	Labour cost and productivity	Capacity changing and switching costs	Incentives, grants and subsidies
Cost of Capital	Taxes		Managerial skills available
Availability and cost of utilities	Investment barriers		Natural hazards based on geography
Competition in factor markets	Transport costs and Infrastructure		Cost of industrial land
Contracting environment	Government and policy regulation		Skills availability
Nearness and quality of material inputs and suppliers			
Demand distance			

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Important factors such as exchange rates, cost of capital, and availability of current utilities are deemed important for the industry to be successfully established, but these are factors for which South Africa has limited influential capabilities for changing. As seen from the market report, most of the leading firms are either in long-term contracts or are expanding mainly through partnerships and agreements. The demand distance to markets in the Asia-Pacific region is unfortunately large and will drive up costs, but through focusing on the right infrastructure and transportation programmes it could be contained. The fact that most major players are conducting new businesses through either merger and acquisitions or partnerships imply there is an opportunity for South African companies to be used as suppliers for cost saving by the bigger firms. This could be supported by the country running programmes, allowing lower labour costs and investing in training to push up productivity. South Africa is in an ideal position to have high-quality inputs and supply of raw materials, for most parts in the steam turbine. South Africa should focus on transport and infrastructure, as it is not ideal yet and if executed correctly can allow for significant cost savings. The factors categorised in the lower section of the right-hand column are considered to be low-hanging fruit, for South Africa to execute properly and save costs on the products. South Africa has a wide spectrum of capabilities and with the right vocational training programmes, the required skills could be acquired at low cost.			
Industry Performance dimensions – Manufacturing (Lead time)			
Demand distance	Infrastructure		
When considering lead time, the demand distance is important, but unfortunately South Africa is limited in implementing changes. South Africa can decrease the lead time through investing in the correct infrastructure as well as by implementing more steps of the supply chain locally.			
Industry Performance dimensions – Manufacturing (Flexibility)			
Contracting environment	Nearness and quality of supporting services	Skilled availability	Nearness and quality of material inputs and suppliers
	Institutions and trust		Capacity changing and switching costs
A niche market requires flexibility related to the delivery and design of products. Thus, the contracting environment is so important, but the buyers have the upper hand in the market and South Africa will have to meet their demand. Nearness and quality of supporting services can help with flexibility and this is a segment that can be promoted and achieved in South Africa, through promoting various segments of the supply chain. Nearness and quality of material is still important, but because South Africa has already achieved this, it is rated in the lower right-hand column and this is nearness and quality of material inputs and supplier. Due to the proximity to the suppliers South Africa is capable of limiting the effect of changing and switching, thus allowing for good overall flexibility.			
Industry Performance dimensions – Manufacturing (Reliability)			
Demand distance	Nearness and quality of material inputs and suppliers	Natural hazards based on geography	
Institutions and trusts			
Infrastructure			

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Reliability from a manufacturing perspective is an important factor for South Africa to achieve due to limitations in the demand, distance to the top markets and the limited bargaining power of suppliers in the market. Through using the benefit of having quality inputs in close proximity and upgrading our infrastructure, South Africa could potentially become a reliable supplier.			
Industry Performance dimensions – Manufacturing (Responsiveness)			
Institutions and trusts	Nearness and quality of supporting services		Nearness and quality of material inputs and suppliers
Contracting environment			Capacity changing and switching costs
The argument for responsiveness is similar to that of reliability. Due to buyers having bargaining power, there is limited influence from South Africa's perspective. Through promoting supporting services and picking the low-hanging fruit in the lower right-hand column, South Africa can achieve a relatively good responsiveness rate.			
Industry Performance dimensions – Manufacturing (Quality)			
Demand distance	Nearness and quality of supporting services		
Targeting the Asia-Pacific market, the demand distance is a high threat due to various factors such as critical design information being lost or damages in transportation. Through merger and acquisitions supporting services can be established in the various countries allowing for a quality support base.			
Industry Performance dimensions – Manufacturing (Sustainability)			
Demand distance	Skills Availability		Nearness and quality of material inputs and suppliers
	Government policy and regulation		
The sustainability of serving markets with high distance is in question, but through establishing the right policies and supporting the various factors that allow for higher performance the factor can be nullified. Skills availability can be constantly grown through the correct research partnerships, collaborations and vocational training.			
Industry Performance dimensions – Research (Responsiveness to leading customers)			
Cultural collectivism, power distance and risk appetite	Skills Availability		
	Quality and scale of science and technology		
Due to the distance from industries there is difficulty responding to new market changes. The best way for South Africa is improving the scale of science and technology central to allowing for quick adoptions. There are limited new product inventions in industry, but perhaps the best method is through radical innovation.			
Industry Performance dimensions – Research (Ability to improve state of the art)			

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Cultural collectivism, power distance and risk appetite	Quality and scale of science and technology	Nearness and quality of supporting services	Skills availability
Location of global centres of excellence	Availability and cost of knowledge assets and technology	Distribution of welfare	
IP regulation		Size, number and location of competitors	
The steam turbine industry is very protective regarding giving away the factors giving them a competitive advantage. This is driven by the intensity of the rivalry between industry players. It can be improved through investing in quality science and technology research and assets. There are currently supporting services available and research skills, which South Africa can leverage to improve the research. South Africa should continue to invest in the CSIR and TBI through the DST, aimed at improving the manufacturing of turbine blades.			
Industry Performance dimensions – Research (Protection of IP)			
IP Regulation	Size, number and location of competitors		
Unfortunately, the industry is very protective of its IP, thus research might struggle at first. For this reason, South Africa should consider collaborations or merger and acquisitions that will allow access to other markets.			
Industry Performance dimensions – Development (Responsiveness to local taste)			
Availability and cost of knowledge assets and technology	Quality and scale of science and technology		Nearness and quality of supporting service
Risk appetite	Skills Availability		
Proximity to manufacturing			
The cost of the required assets and technology remains high and South Africa is not known for taking major risks. South Africa can contribute towards investing in science and technology centres and to consider manufacturing most parts in the supply chain, which will be beneficial, as the proximity to manufacturers are better and upgrades can be implemented effectively. The supporting services and skills availability can also be improved with relative ease.			
Industry Performance dimensions – Development (Protection of IP)			
IP Regulation	Size, number and location of competitors		
Due to the distance and newness of the market the competitors and their location are far away and can feed off each other's development, but in the same breath the protection of IP is of utmost importance, making it difficult to learn from each other, hence nullifying size and location of competitors and allowing research to take place freely in South Africa, as there are fewer competitors to steal ideas.			

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J.4 Appropriateness evaluation of the interventions

A brief illustration is shown below of how the policies to target the key factors, especially related to the LT quadrant, can be classified. Only dimensions 2 and 3 are shown, as each of them has been established with the goal of serving dimension 1 to drive down the costs that will help improve South Africa to win market share.

Table J.2: Applicable areas to be used when targeting factors adapted from (Landesmann and Stöllinger, 2018)

Characteristics	**Policy Areas**				
	Technology Policy	Labour/Human Capital	Finance	Industry/ Competition	Infrastructure
Technology/ Productivity Level	**Dimension 2**: Spill-overs to domestic capabilities	**Dimension 2:** Vocational training programmes	**Dimension 3a:** Support for domestic new entrants: bank-based finance	**Dimensions 2, 3:** Cluster policy; importance of FDI and spillover	**Dimension 3a**: Link up with IPNs: Transport and communications
Country size	**Dimension 3c:** International collaborations	**Dimension 2:** Importance of complementary foreign and domestic expertise			**Dimension 3a:** Intra-country and international connectivity
Raw-Material-Based	**Dimension 3a:** Build up know-how in processing stages; diversify in neighbouring industrial fields	**Dimension 2:** Training personnel to support upgrade and diversification.			
Geographic location	**Dimensions 2, 3:** Use channels of interaction: FDI, researcher collaborations	**Dimension 3b, c:** Build up longer-term training & research collaborations; tailor vocational training and higher education to needs of C.A. industries		**Dimension 3a**: International production networks, strategic supplier and outsource options.	
Political economy: Institutional/legal standards		**Dimensions 2, 3:** Build up meritocratic, well-resourced special training and educational institutions			**Dimensions 2, 3a**: Specific supervision of infrastructure projects; with assistance of foreign donors

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