

Industrial policy-making in mineral-rich developing countries

by

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification. This dissertation has also been presented at KU Leuven in terms of a joint-degree agreement.

This dissertation includes 6 original papers published in either peer-reviewed journals (4) or peer-reviewed conference proceedings (2) and 1 unpublished publication. The development and writing of the papers (published and unpublished) were the principal responsibility of myself and, for each of the cases where this is not the case, a declaration is included in the dissertation (Appendix **B**) indicating the nature and extent of the contributions of co-authors.

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Abstract

This dissertation investigates policy-making in mineral-rich developing countries with a focus on policies that seek to promote the value add to mineral products before export (also known as beneficiation policy). Firstly, it explores how mineral value chains may be conceptualised to frame the debate around beneficiation policy and enable a holistic contextualisation of such policy. Secondly, it presents two novel/adapted analytical frameworks that support the appraisal of the potential strategic value of different downstream processing activities. The first framework uses corporate sustainability disclosures to assess the potential triple-bottom line impact of hosting a focal activity within a particular jurisdiction. This framework is applied to the case of platinum in South Africa in order to illustrate how it may be applied. The second framework provides an input-output lens with which to leverage the product space analysis method to determine how difficult it would likely be to target an industry and what the potential capability development and economic growth effects of this industry could be. This framework is applied to the case of steel in South Africa. The case is used to reflect on the optimality of following a downstream linkage-based (beneficiation) industrial policy logic. It is found that a so-called ‘leap-frogging’ approach to policy development may be more optimal. Finally, this dissertation presents a framework to enable the appraisal of the factors driving the location of a particular activity to understand how such an activity could be targeted. This supports the attainment of a first approximation of the cost and feasibility of the required interventions to attain this activity in a mineral-rich developing country. This dissertation therefore contributes towards consolidating and extending the academic literature that has a bearing on improved industrial policy-making in mineral value chains of mineral-rich developing countries. Furthermore, it aims to provide practical tools for policy-makers in order to support improved developmental outcomes. It is also envisioned that the tools and approaches developed in this dissertation could be leveraged far beyond just the mineral related industries which were the focus of this study.

Opsomming

Hierdie proefskrif ondersoek beleidmaking in mineraal-ryk ontwikkelende lande, met die klem op beleid wat die waarde toevoeging tot minerale produkte voor uitvoer bevorder (ook bekend as veredelingsbeleid). Eerstens word ondersoek hoe minerale waardekettings gekonseptualiseer kan word om die debat rondom veredelingsbeleid te raam en 'n holistiese kontekstualisering van sodanige beleid moontlik te maak. Tweedens, word twee nuwe/aangepaste analitiese raamwerke voorgelê wat die evaluering van die potensieële strategiese waarde van verskillende stroomafverwerkingsaktiwiteite ondersteun. Die eerste raamwerk gebruik korporatiewe volhoubaarheids-openbaarmakings om die potensieële driehoek-impak van 'n fokale aktiwiteit binne 'n bepaalde jurisdiksie te assessee. Hierdie raamwerk word toegepas op die geval van platinum in Suid-Afrika ten einde te illustreer hoe dit aangewend kan word. Die tweede raamwerk bied 'n inset-uitsetlens vir die aanwending van die produkruimteanalise metode wat dit moontlik maak om te bepaal hoe moeilik dit waarskynlik sal wees om 'n bedryf te teiken en wat die potensieële vermoë ontwikkeling en ekonomiese groei-effekte van hierdie bedryf kan wees. Hierdie raamwerk word toegepas op staal in Suid-Afrika. Die gevallestudie word gebruik om te besin oor die optimaliteit van die volg van 'n stroomafverbindingsgebaseerde, oftewel veredelingsgebaseerde, industriële beleidslogika. Daar word bevind dat 'n sogenaamde 'padda-sprong'-benadering tot beleidsontwikkeling meer optimaal kan wees. Ten slotte word daar in hierdie proefskrif 'n raamwerk voorgestel vir die evaluering van die faktore wat die ligging van 'n bepaalde aktiwiteit beïnvloed, om sodoende te bepaal hoe so 'n aktiwiteit geteiken kan word. Dit ondersteun die bereiking van 'n eerste benadering van die koste en haalbaarheid van die nodige ingrypings om hierdie aktiwiteit in 'n mineraal-ryk ontwikkelende land te ontwikkel. Hierdie proefskrif dra dus by tot die konsolidering en uitbreiding van die akademiese literatuur wat betrekking het op verbeterde nywerheidsbeleidmaking in minerale waardekettings van mineraal-ryk ontwikkelende lande. Verder is dit daarop gemik om praktiese instrumente vir beleidmakers te verskaf ten einde verbeterde ontwikkelingsuitkomstes te ondersteun. Daar word ook beoog dat die gereedskap en benaderings wat in hierdie proefskrif ontwikkel word, ook buite die mineraalverwante bedrywe, wat die fokus van hierdie studie was, aangewend kan word.

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Dedications

This dissertation is dedicated to my daughter, Olivia. May you find joy in knowledge and your curiosity never be stifled.

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Nomenclature

DMR	Department of Mineral Resources
DST	Department of Science and Technology
DTI	Department of Trade and Industry
ECI	Economic Complexity Index
FDI	Foreign Direct Investment
GMVC	Global Mineral Value Chain
GPN	Global Production Network
GRI	Global Reporting Initiative
GVC	Global Value Chain
GVN	Global Value Network
IO-PS	Input-Output Product Space
IPO	Investment Promotion Agency
MIT	Massachusetts Institute of Technology
MNE	Multinational Enterprise
MVC	Mineral Value Chain
NCT	Neo-Classical theory
NRF	National Research Foundation
NEG	New Economic Geography
NGO	Non-Governmental Organisations
OECD	Observatory for Economic Complexity
PCI	Product Complexity Index
PGM	Platinum Group Metal
PhD	Doctor of Philosophy
RCA	Revealed Comparative Advantage
R&D	Research and Development
REE	Rare Earth Element
SAIIE	Southern African Institute for Industrial Engineering
SJR	SCImago Journal Rank
SWOT	Strengths, Weaknesses, Opportunities and Threats

NOMENCLATURE

x

TBL	Triple Bottom Line
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
WTO	World Trade Organisation

Chapter 1

Introduction

Beneficiation - the value add to minerals in the country of extraction before export (Department: Trade and Industry, 2014) – has been a contentious subject of debate for decades. On the one hand, resource nationalists have argued that mineral extracting countries should seek to locally process minerals into fully fabricated products in order to gain the maximum benefit from their resource endowments (Humphreys, 2013). On the other hand, a neoliberal analysis of the matter would suggest that to intervene in terms of where minerals are processed could lead to a global reduction in welfare and would thus not be a justified course of action.

Furthermore, academia seems to be divided on the merits of pursuing beneficiation (or downstream mineral processing) as rationale for development. Morris *et al.* (2012b), though acknowledging the possible value of downstream linkages, propose rather focussing on upstream linkages (the industries that produce products for consumption in the mining industry). Furthermore, most of the literature addressing beneficiation (or downstream linkages) have done so in passing and have not provided policy-makers with the analytical tools necessary to guide beneficiation policy to optimally support development.

This has meant that the guidance for policy has often remained purely ideological. Nonetheless, various examples of beneficiation/downstream linkage policies exist. Indonesia pursued a rather extreme downstream linkage strategy seeking to force companies to locally add value to minerals before exporting them (Humphreys, 2013). Similarly, China leveraged its market dominance of rare earth elements to force downstream linkages (Zhang *et al.*, 2015). Botswana developed its diamond cutting and polishing industry by making De Beers' mining license dependent on the establishment of downstream processing activities (Morris *et al.*, 2012a). Furthermore, the Philippines, Zimbabwe and South Africa have all considered implementing policies geared towards encouraging the downstream processing of minerals (Beckmann, 2013; Eunomix, 2015; Department of Mineral Resources, 2011).

Given the significant importance of minerals to the developing world and the potentially far-reaching consequences (both positively and negatively) of

beneficiation policies, this research seeks to improve the guidance available to policy-makers when considering beneficiation policies. In particular, this research seeks to move beyond the confines of the analytical approaches that have been applied to the beneficiation debate, with limited success to date, in order to provide an extended perspective that could support more profound insights. This research is thus exploratory and arguably rather ambitious in intent.

The research is approached by first evaluating how to contextualise and conceptualise beneficiation to reduce the assumptions made with respect to its merits and drivers, and to position it within the broader context of economic development within a country. By doing this, two fundamental questions that are key to providing better guidance in terms of beneficiation policy with regards to any particular case (i.e. focal value chain and country) are identified. These are: i) would it be strategically valuable to attempt to attain a particular processing activity within the value chain?; and ii) could the mineral producing country attain this activity (if it is deemed to be strategic) and, if so, how might it be able to do so? The first question relates to whether the activity contributes to economic growth, job creation or some other strategic objective(s) of a mineral producing country. The second question relates to the drivers of the location of the activity and the cost and feasibility of intervening to alter the outcomes of these drivers. Only when both these questions are considered in tandem, can a decision be made regarding whether intervention would be justified to attempt to attract/attain the local execution of a particular mineral processing activity.

Having identified these two questions that fundamentally underpin the merits/demerits of beneficiation, this dissertation explores how these questions might best be answered for any specific case. In particular, new analysis avenues are explored in order to assess whether they can provide new insights with regard to the two identified questions. In so doing, this dissertation contributes to the suite of tools available to policy-makers to address each of these questions in order to support improved policy-making regarding downstream mineral processing.

Hence, the research explores three related research themes. Firstly, conceptualising and contextualising mineral value chains in a way that enables a framing of the beneficiation debate. Secondly, exploring analysis avenues for determining the strategic value of a particular mineral processing activity. Finally, exploring how mineral-rich countries may go about analysing the requirements for and feasibility of attaining activities that hold promise. Within all three themes, existing analytical approaches are found to fall short when applied to the question of beneficiation. Hence, new analytical tools and/or adaptations of existing analytical perspectives are developed within each of the research themes to address these shortcomings and shed new light on the beneficiation question.

1.1 Research Aim and Objectives

The primary aim of this research is to frame the debate regarding beneficiation (downstream linkages from mining) and, based on this framing, to develop new analytical tools to facilitate improved beneficiation related policy-making. This research aim is supported by three objectives, namely, to:

1. develop a conceptualisation of mineral value chains that frames the beneficiation debate and enables a holistic contextualisation of downstream mineral processing policy;
2. develop new/adapted analytical frameworks that provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities; and
3. develop a new analytical framework that enables the appraisal of the factors driving the location of particular downstream mineral processing activities to understand how such activities could be targeted (and thus attain a first approximation of the cost and feasibility of doing so).

1.2 Dissertation outline

Despite significant policy attention, beneficiation has received comparatively little research attention. One of the dominant frameworks that has been used as a starting point in beneficiation related studies has been the linkage theory framework grounded in the work of [Hirschman \(1958, 1981\)](#). This perspective evaluates the impact of mining by considering the various “linkages” from mining activities. These include fiscal linkages, consumption linkages and production linkages (both forward/downstream and backward/upstream). Beneficiation then falls under the forward linkages from mining. Using this perspective has various pitfalls. Firstly, it uses mining as an anchor and thereby implies a very narrow definition of beneficiation (i.e. only the processing stages directly linked to mining and taking place in the locality of the mine are generally considered). Secondly, the linkage perspective generally focusses only on the direct economic impact associated with linkages. This means that the other dimensions of impact (e.g. social and environmental) are generally not considered, nor are the potential negative impacts of beneficiation. Third, as forward linkages are only one of the potential linkages from mining, linkage-based studies rarely focus only on beneficiation thereby limiting the thoroughness of these studies in terms of analysing beneficiation. Furthermore, given the lack of clarity on beneficiation policy in the literature, it is clear that the existing approaches have not been particularly successful in addressing the uncertainties regarding the issue.

Hence, it was deemed necessary to evaluate the concepts and literature pertaining to beneficiation without first adopting any of the current theoretical focussing devices except a broad interpretation of the value chain concept. Consequently, it was required to inductively synthesize the literature related to mineral value chains into a novel conceptual framework that was as holistic as possible. The result of this process is presented in Chapter 2. Feedback from the peer-review of the article presented in Chapter 2 highlighted an opportunity to further contextualise the proposed framework in the existing global value chain (GVC) literature. Hence, Appendix A explores how the key concepts from Chapter 2 (namely the assessment of both positive and negative value capture from activities) could be integrated into the existing GVC analysis frameworks.

From the conceptualisation of the mineral value chain presented in Chapter 2, two questions were identified to be critical to guiding beneficiation policy. Firstly, how might the strategic value of particular mineral processing activities be determined? Secondly, how might the factors driving the location of particular downstream mineral processing activities be determined in order to understand how such activities could be targeted (thus enabling a first approximation of the cost and feasibility of doing so)?

In the literature on beneficiation, very little guidance exists in terms of determining the strategic value of particular processing activities. Consequently, this research turned to the literature regarding the determination of the strategic value of developmental industries in general. However, there is also limited guidance in terms of how the strategic value of industries in general should be assessed apart from through the use of detailed ad-hoc feasibility studies. Hence, novel approaches were explored in order to address this gap. The first promising approach that was further explored was the use of public sustainability disclosures. Given the rise of the use of these disclosures and their inclusion of all three dimensions of the triple bottom line, it was investigated whether they might be able to provide insights regarding the developmental potential of industries. In order to test this approach to establishing the developmental potential of industries, it was first necessary to assess the available public sustainability disclosure frameworks in terms of their suitability for this purpose. This analysis is presented in Chapter 3. In this chapter, the GRI G4 framework is identified as the most suitable for the intended aim. Consequently, Chapter 4 explores how the GRI G4 framework might be leveraged to assess the strategic value of developmental sectors. Furthermore, the chapter includes a case study on the platinum industry – specifically focussing on autocatalysts and jewellery. Based on the case study, a SWOT (strength, weaknesses, opportunities and threats) analysis of the framework is performed. Despite the ability of the approach to compare the developmental impact of industries, it still has various weaknesses in terms of guiding industrial policy in general and beneficiation policy in particular.

Consequently, another approach – the product space analysis approach –

was also evaluated for its potential to guide beneficiation policy by identifying the strategic value of industries (though only focussing on the economic dimension). It is argued that the existing product space analysis approach holds the potential of achieving this aim, but that it would need to be adapted to be suitable to the level of analysis required to guide beneficiation policy. Hence, Chapter 5 proposes how this might be accomplished and presents a case study on the steel value chain in South Africa. This case also sheds new light on the optimality of beneficiation by arguing that a “leap-frogging” approach to industrial policy might be more optimal than a strict beneficiation-based approach.

Two novel ways of evaluating the strategic value of developmental industries in general, and downstream mineral processing industries in particular, are thus presented in Chapter 4 and Chapter 5. The main advantage of the framework presented in Chapter 4 is, arguably, that – in addition to considering the economic related aspects of these industries – the social and environmental dimensions are also taken into account. On the other hand, the analysis in Chapter 5 can be performed more rapidly, can cover more industries simultaneously, provides an approximation of the “difficulty” of acquiring an industry and identifies a theoretically ideal developmental path (though it only focusses on economic growth, without considering social and environmental factors). Together, these frameworks significantly extend the current suite of tools available to policy-makers that enable the rapid comparison of the strategic value of different developmental sectors.

Although Chapter 4 and Chapter 5 provide new frameworks for the evaluation of the strategic value of different developmental industries, they have relatively little to say in terms of whether these industries could be successfully developed within a particular country (though the framework in Chapter 5 does refer to a proximate “distance”) and even less regarding *how* these sectors might be targeted. Similarly, little guidance exists in the beneficiation literature regarding how a particular industry might best be supported. Consequently, Chapter 6 provides a research agenda regarding what would be necessary to determine how a particular industry might be supported. In particular, it is argued that a detailed understanding of the factors that drive the global location of the activity needs to be established. Furthermore, it is argued in Chapter 6 that the existing beneficiation literature does not sufficiently address this issue. Accordingly, Chapter 7 presents a review of six fields of literature that address the location of economic activities. Based on this review an inductive consolidation of the factors that drive the location of economic activities is provided in the form of a framework. This framework is then positioned as a foundation for policy-makers to establish whether it would be feasible – and what would be required – in order to successfully target a particular downstream mineral processing activity, or any other economic activity.

Taken together, these chapters thus aim to frame the debate regarding

beneficiation and, based on this framing, explore the use of analytical tools in order to facilitate improved beneficiation related policy-making. In particular, the dissertation provides new frameworks for evaluating the strategic value of industries and the requirements for becoming competitive in these industries. The implications of the research are further discussed in Chapter 8, which also reflects on how the aim of this research was achieved in this dissertation and what still remains to be done in future research.

1.3 Methodology employed in the dissertation

The research presented in this dissertation is exploratory in nature and oriented towards solving a particular problem – namely, the suboptimal development of beneficiation policy in mineral-rich developing countries, which is at least partially due to a lack of efficient tools for supporting improved decision-making with regards to beneficiation policy. Hence it is not primarily concerned with theory development or testing. Rather, it is, on an abstract level, similar in aim to the relatively well-known dissertation by Osterwalder (2004) insofar as it seeks to develop best-practice artefacts that solve a particular practical problem. Similar to the work by Osterwalder (2004), this dissertation (when viewed in its entirety) can thus be categorised as primarily taking a design science research approach. Design science is an ideal research approach when the goal is to tackle problems that are “ill-structured” in a manner that is systematic and inter-disciplinary in nature (Holmström *et al.*, 2009). *Design science* can be defined as research that seeks “i) to explore new solution alternatives to solve problems, ii) to explain this explorative process, and iii) to improve the problem-solving process (Holmström *et al.*, 2009).

Peffers *et al.* (2006) (see also Peffers *et al.* (2007)) introduce a design science research process model that consists of six main stages. The essence of these stages are: i) identify problem and show importance; ii) define objectives of a solution; iii) design and develop artefact that seeks to achieve these objectives; iv) demonstrate use of artefact by applying it to a suitable problem/case; v) evaluate the performance of the artefact in terms of how effective and efficiently it meets the objectives of the solution; and vi) communicate results. This process model was essentially followed iteratively for the purposes of this dissertation. Chapter 2 and Appendix A together present a first iteration focussed on developing and testing an artefact that is able to improve the framing of the beneficiation debate. Chapter 3 and 4 present another iteration that seeks to develop and test an artefact that enables the assessment of the strategic value of developmental industries. Chapter 5 presents a third iteration of this process that also seeks to develop and test an artefact that enables the assessment of the strategic value of developmental industries. Finally, chapters 6 and 7 present a partial iteration of this process that seeks to develop an artefact that enables the assessment of how a strategic sector

might be targeted. The completion of the iteration by refining and evaluating the framework by means of application is recommended for future research.

1.4 Structure and format of the dissertation

Chapters 2 to 7 and Appendix A each contain either a published or unpublished article. In each case these are prefaced by an introduction and followed by a summarising conclusion to provide a link between the different chapters and to ensure that the portfolio of articles forms a cohesive unit. These chapters are followed by a summary chapter highlighting, inter alia, the scientific contribution of the study (Chapter 8). Table 1.1 provides an overview of the articles that comprise Chapter 2 to Chapter 7. In particular, for each article, the table indicates which of the dissertation objectives it links to, elaborates on its objectives, summarises the key methodologies employed, provides its reference and clarifies its publication status. Figure 1.1 also provides an overview of how each of the article chapters relate to each of the research objectives and is used throughout the dissertation to assist with navigating the dissertation.

The PhD candidate was the only author for the article in Chapter 2. Furthermore, the PhD candidate was the first author for the articles in Chapters 5, 6 and 7 and Appendix A which were each co-authored with either one or two of the promoters of the candidate's PhD. Furthermore, the candidate was the second author for the articles in Chapters 3 and 4, which were co-authored with a masters student working under the supervision of the PhD candidate. Detailed contribution declarations for each article are contained in Appendix B.

The articles that have been published with open access copyright licences are all included in the dissertation in their published form with added headers at the top of each page to assist in navigating the PhD (Chapters 2¹, 3² and 4³ and Appendix A¹). Two included articles have been published with licences other than open-access. One is included in the dissertation in its published form due to the publisher's allowance of such publication in a dissertation⁴ (Chapter 6). For the other article, the authors' accepted manuscript version of the article is included with permission from the publisher (Chapter 5). Finally, the one article which had not yet been accepted for publication by the date of publication of this dissertation is provided in preprint/author original manuscript (AOM) form and does not contain any improvements based on peer review (Chapter 7).

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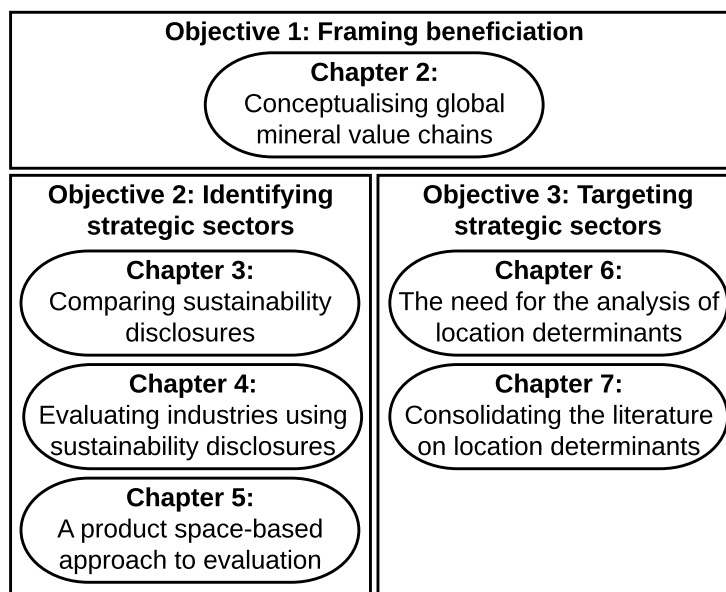


Figure 1.1: Overview of each chapter's relation to the three research objectives.

Table 1.1: Overview of the articles that comprise Chapter 2 to Chapter 7

Research Objective	Chapter	Chapter objectives	Methods	Reference	Publication status
1) Develop a conceptualisation of mineral value chains that frames the beneficiation debate and enables a holistic contextualisation of beneficiation policy.	Chapter 2	1) Inductively reconceptualise mineral value chains to contextualise beneficiation debate.	Inductively construct conceptualisation based on literature review.	Bam, W. (2016). 'Conceptualising Global Mineral Value Chains: A Tool for Mineral Policy Design'. SAIIE27 Proceedings, pp. 61–73.	Published open-access
2) Explore analysis avenues that might provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities.	Chapter 3	Evaluate public sustainability disclosure framework for use as basis for comparing developmental opportunities.	Literature review; Comparative analysis	Du Plessis, J. A., & Bam, W. G. (2017). 'Scoping Phase Comparison of Development Opportunities by Making Use of Publicly Available Sustainability Information', <i>Procedia Manufacturing</i> , 8: 207–14.	Published open-access
	Chapter 4	1) Construct a development opportunity assessment framework based on the GRI G4 disclosure framework. 2) Apply framework to platinum industry. 3) Assess SWOT of framework.	Review best practices to design framework; Validate framework with industry experts; Test application with case study	Du Plessis, J., & Bam, W. (2018). 'Comparing the Sustainable Development Potential of Industries: A Role for Sustainability Disclosures?', <i>Sustainability</i> , 10(3)/878: 1–30.	Published open-access
	Chapter 5	1) Adapt product space analysis approach to enable detailed analysis of beneficiation policy. 2) Apply approach to case of steel in South Africa. 3) Evaluate implications of results for beneficiation policy.	Artefact design and development; Refine and evaluate through case study	Bam, W., & De Bruyne, K. (2018). 'Improving Industrial Policy Intervention: The Case of Steel in South Africa', <i>The Journal of Development Studies</i> . DOI: 10.1080/00220388.2018.1528354	Published
3) Explore analysis avenues that might enable the appraisal of the factors driving the location of particular downstream mineral processing activities in order to understand how such activities could be targeted.	Chapter 6	1) Review beneficiation literature to determine existing guidance in terms of targeting industrial policy. 2) Identify possible gaps in literature. 3) Suggest research agenda to address these gaps.	Critical literature review	Bam, W., & De Bruyne, K. (2017). 'Location policy and downstream mineral processing: A research agenda', <i>Extractive Industries and Society</i> , 4/3: 443–7.	Published
	Chapter 7	1) Based on agenda in Chapter 6, draw on wider body of literature to better understand the factors that drive the location of economic activities. 2) Synthesize reviewed literature into conceptual framework that can guide the evaluation of industries.	Structured literature review; Inductive synthesis of conceptual framework.	Bam, W. G., De Bruyne, K., & Schutte, C. S. L. (2019). 'A review of factors affecting the location of economic activities: a multi-disciplinary approach'.	Submitted

Chapter 2

A framework for conceptualising global mineral value chains

This chapter addresses the first objective of this dissertation, namely to “develop a conceptualisation of mineral value chains that frames the beneficiation debate and enables a holistic contextualisation of downstream mineral processing policy”. This chapter consists of three sections. Section 2.1 situates the chapter within the narrative of the dissertation (as summarised in Figure 2.1). Section 2.2 contains the article which comprises the primary part of this chapter. Finally, Section 2.3 concludes the chapter by summarising its contribution to the dissertation.

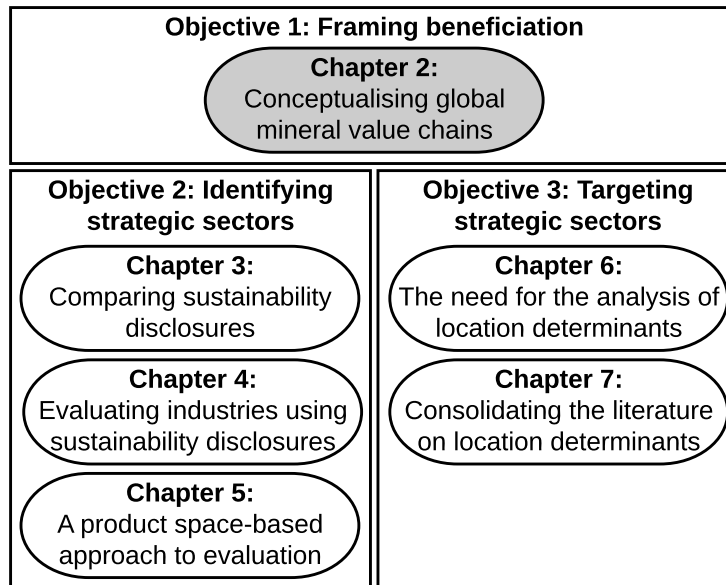


Figure 2.1: Position of Chapter 2 in dissertation.

2.1 Introduction: Chapter 2

Chapter 1 identified shortcomings of the current debate regarding beneficiation. In particular, it was highlighted that much of the literature addressing beneficiation (or downstream linkages) have done so in passing and have not provided policy-makers with the analytical tools necessary to guide beneficiation policy to optimally support development. In particular, the need was identified to extend the existing analytical approaches that have been applied to the beneficiation debate in order to provide new perspectives that could support more profound insights.

Towards this ambition, this chapter considers how to contextualise and conceptualise beneficiation to reduce the assumptions made with respect to its merits and drivers and to position it within the broader context of economic development within a country. Hence, this chapter seeks to contribute towards addressing the first objective of this research, namely to “develop a conceptualisation of mineral value chains that frames the beneficiation debate and enables a holistic contextualisation of downstream mineral processing policy”. This is approached by evaluating the concepts and literature pertaining to beneficiation and inductively synthesising the literature related to mineral value chains into a novel conceptual framework that is as holistic as possible.

The emerging framework provides a perspective on how mineral value chains and the value capture derived from them may be conceptualised. The framework highlights the distinction between where activities take place and the value capture that may be obtained from them. It also highlights the factors that affect both the location of mineral extraction related activities and the value capture from these activities.

2.2 Article: “Conceptualising global mineral value chains: a tool for mineral policy design”

The article presented in this section is the published version of peer-reviewed article published in the proceedings of the *Southern African Institute for Industrial Engineering’s* 28th annual conference. The local conference provided the ideal opportunity for the candidate to expose the conceptualisation to peer-review and the linked conference provided the opportunity for the candidate to engage with and get feedback from the local industrial engineering research community. The full conference proceedings are available at: <http://www.saiie.co.za/cms/attachment/665>.



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CONCEPTUALISING GLOBAL MINERAL VALUE CHAINS: A TOOL FOR MINERAL POLICY DESIGN

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ABSTRACT

This paper presents a model by which policy makers can conceptualise the shape and impact of mineral value chains (MVCs) and how their decisions influence the local footprint and value capture of mineral related activities. The model combines a high-level value chain perspective with the triple bottom line dimensions of sustainable development. The proposed model aims to stimulate increased discourse surrounding a more holistic view of value capture from mineral value chains. This is done by investigating the role of productive actors, government and civil society and how each of these players' roles interlink.



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1. INTRODUCTION

The last fifty years have seen the metals producing and consuming nations moving into different camps, with the major consumers no longer being the major producers. This has led to consumer countries increasingly moving to adopt policies that ensure the supply security of critical minerals. On the other hand, producing countries have increasingly become prone to resource nationalism and the adoption of policies that aim to maximize the benefit achieved from the extraction of their resources [1]. However, this is often a difficult task where there may be trade-offs between short to medium term value for the nation and the long term sustainability of their resource activities [2].

In some cases, this resource nationalism has found expression in policies that are aimed at localising the downstream processing of minerals to the mineral producing countries. The reasoning behind this usually being that the local processing of minerals will result in greater economic value add, an improved balance of trade and the creation of more jobs [1-5].

Academia has also been investigating several aspects regarding the increased sustainable value capture from mineral resources in support of the drive to ensure more benefit from mineral endowments for mineral producing countries and to combat the so called “resource curse”. This has included research on aspects ranging from the role of corporate social responsibility (CSR) in development [6, 7], managing small scale and artisanal mining (ASM) for improved regional outcomes [8], trust between different stakeholders in promoting sustainable development [9] and incentivising the recycling of minerals [10].

However, there appears to have been limited recent attempts to collate the research into a conceptual framework to enable policy makers to consider the wide ranging impacts of their resource policies in a holistic manner. This is particularly important due to the increased emphasis on localising mineral processing activities where multiple factors need to be considered. The nearest to such a framework that the author is aware of is the conceptualisations suggested by Franks et al. [11] for representing cumulative impacts in resource regions, presented in their introduction of the special issue of the journal, *Resources Policy*, on ‘Understanding and Managing Cumulative Impact in Resource Regions’.

This paper aims to address this gap by proposing a model conceptualising mineral value chains (MVCs) with a focus on the downstream processing of extracted minerals, the value capture from the local MVC footprints and the factors that influence both the location of and value capture from mineral processing activities. The framework combines a high-level value chain perspective similar to that used by authors such as Gereffi and Lee [12] and Barrientos et al. [13] with the triple bottom line (TBL) dimensions of sustainable development (economic, social and environmental) that has become increasingly important in various areas of research [14].

From this dual perspective, the conceptual model was inductively constructed through reviewing 304 articles published in the journal *Resources Policy*. These articles were selected by reviewing all the articles published in this journal since the start of 2010 up until the 12th of July 2015. The identification of these articles was based on a Scopus® search on the latter date for all articles from this journal, filtered by the requirement of being published in or after 2010. Instead of delivering the final word, the proposed model aims to stimulate increased discourse surrounding a more holistic view of value capture from mineral value chains, particularly for mineral rich countries and to provide policy makers with a starting point from which to consider their mineral related policies.

The first element of the conceptual model, presented in Section 2, focuses on the elements of a mineral value chain. The second element of the conceptual model, presented in Section 3, is the national value capture from mineral value chains. The third element of the conceptual model, presented in Section 4, focuses on the factors that influence the shape of the mineral value chain.

The final element of the model focuses on the factors that influence the value capture from mineral value chains, presented in Section 5. In Section 6, these four elements are collated into a single conceptual model. Finally, Section 7 provides concluding remarks to the article.

2. CONCEPTUALISATION OF THE MINERAL VALUE CHAIN

There are various ways in which to conceptualise a mineral value chain. The specific focus of a study, the mineral considered and the types of policies being investigated will dictate which of these conceptualisations may be more applicable. This section presents a typical conceptualisation of the MVC for the investigation of the location mineral processing activities. Thereafter, other considerations that might be important in the current mineral related policy environment are discussed.

In order to analyse the location of downstream mineral processing activities, the proposed conceptualisation integrates the theoretical work of Humphreys [1] focussing on the tension between producing and consuming



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countries for control over the processing steps of the mineral value chain and the GVC conceptualisation work of authors such as Gereffi and Lee [12] and Barrientos et al. [13]. This proposed conceptualisation is shown in Figure 1.

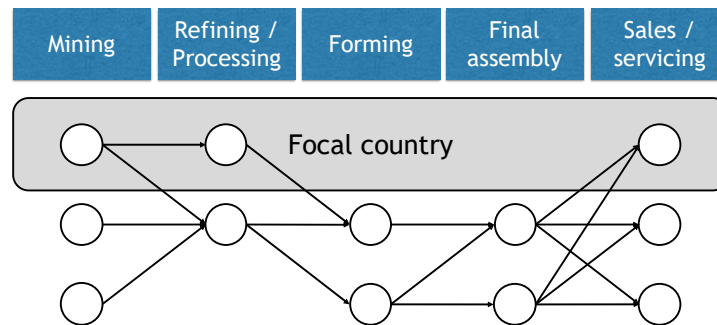


Figure 1: Proposed conceptualisation of the local footprint of the mineral value chain within a global context.

This conceptualisation allows for the evaluation of the structure of MVC by distinguishing between the extraction source of the mineral and the market where the products using this mineral are eventually used or consumed. Between these two poles, the model allows for the evaluation of where manufacturing takes place - in the focal country or not. It could be expected that the refining and processing takes place close to the extraction activity in order to minimize the costly transport of unprocessed ore. It could also be expected that the final assembly might take place close to large final markets in order to minimize the transport cost and lead times to the final consumers. The manufacturing, forming and assembling might take place somewhere in between, though this need not be the case, and different factors play a role in determining where these activities are located.

By conceptualising the MVC in this way, it is possible to glean new insights regarding the location of MVC activities and the drivers of this location. This high level conceptualisation will have to be adapted for different minerals depending on the different and possibly parallel processing steps, the importance of recycling and other mineral specific properties.

Other considerations that might be important in the current mineral policy environment include the distinction between large scale and artisanal mining (ASM), the clustering of activities, linkages and the mineral life cycle. These are briefly discussed here in turn.

Recent literature emphasises the distinction between and consideration of both large scale conventional mining and artisanal and small scale mining (ASM). The failure to distinguish and accommodate both can lead to sub-optimal outcomes, particularly on the local social level [8, 15-27].

Another important consideration is the clustering of activities. Activity clusters can generate critical mass and unlock positive feedback loops that generate additional growth and activities. They can also assist in overcoming constraints through the pooling of resources. However, due to the often observed mining revenue flow to cities, abroad to shareholders and to fly-in fly-out employees and the flow of royalties to national governments, these clusters are often not allocated sufficient resources and underexploited. This can lead to the suboptimal development of mining regions [24, 28-36].

Related to clusters is the consideration of linkages. Linkages (both upstream and downstream) are also important in terms of the shape of MVCs. Increasing them allows governments to increase the local footprint of MVCs and the value capture from them [37]. Fessehaie [30], Morris et al. [37] and Hanlin and Hanlin [38] emphasise the importance of “deeper” upstream linkages that stretch beyond the first tier to ensure that the maximum local activity footprint is achieved.

Toward better environmental management, Fleury and Davies [39] conceptualises the MVC as part of a wider life cycle. This life cycle starts with the societal demand for minerals and includes the disposal, reuse and recycling of minerals. By conceptualising minerals in this way, policy makers can consider the effects of minerals after extraction to the point of disposal.

This section presents a generic conceptualisation of the MVC to analyse the location of mineral processing activities. Thereafter, other considerations that were identified during the literature review that may be important to incorporate into a MVC conceptualisation for other policy related studies were identified. The



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following section extends the proposed view of the MVC by incorporating the sustainable value capture dimensions of the triple bottom line.

3. NATIONAL VALUE CAPTURE FROM MINERAL VALUE CHAINS

The value that is captured from the local footprint of MVC activities can be conceptualised according to the three sustainability dimensions of the *triple bottom line* (TBL) concept, popularised by Elkington [40]. Each of these dimensions can also be conceptualised as entailing gain and cost, as the complex impacts of mineral related activities can have both positive and negative effects on the host nations. This is illustrated in Figure 2.

The triple bottom line, consisting of an economic, social and environmental dimensions, has been increasingly used in supply chain literature and provides a useful conceptualisation of the aspects related to the sustainability of a variety of activities and how these activities translate to value [41-44]. The distinction between gain and cost is somewhat problematic, as choosing in which category certain impacts fall might be a matter of perspective. However, the goal of distinguishing between the two categories is to support decision-making by ensuring the consideration of both positive and negative aspects. A number of aspects can be identified to form part of each of these dimensions of value capture. These are each considered in Section 3.1 through 3.3.

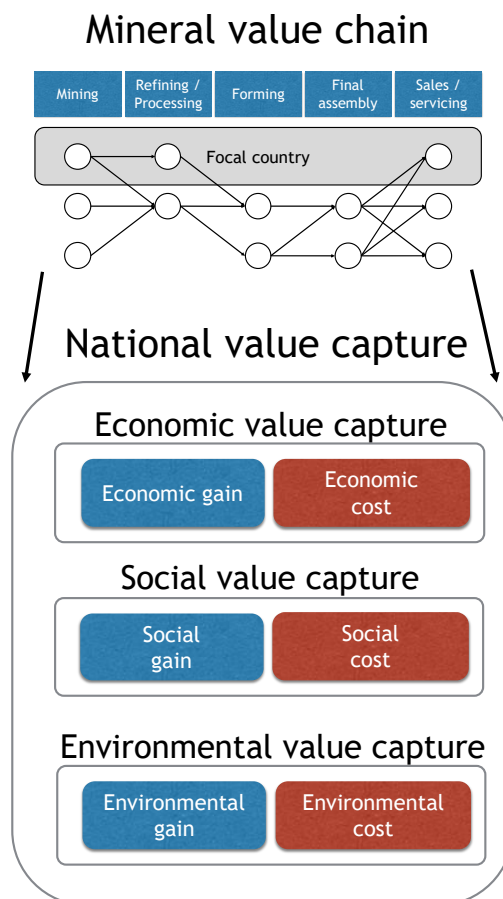


Figure 2: The national value capture from the local resource value chain footprint.

3.1 Economic value capture

Some direct economic benefits from mineral related activities cited in literature include capital investment [32, 45, 46], employment sustained [1, 29, 32, 46-48], economic growth [32], improved income levels [1, 32, 46, 48, 49], local development, lower inequality [48, 50], shareholder returns [32], tax revenue [1, 21, 32, 51, 52] and local value added [47]. Indirect economic benefits include the appreciation of the national currency [32], a diversification of exports [53], the stimulation of downstream activities, employment in other sectors,



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particularly in transport, rental and accommodation [1, 29, 36, 54], infrastructure development [37, 45] and other linkages [4, 5, 32, 37, 38, 45, 46, 55-62].

There may also be several economic costs related to the exploitation of minerals that should be considered. These have been identified to include the opportunity cost, which is particularly important due to the relatively capital intensive nature of mining and thus might translate to fewer jobs for the equivalent investment [32, 54], the exhaustion of minerals [32], the outflow of revenue to foreign investors [28], low job spill-overs into manufacturing and agriculture [54], poorer financial development [63], regional economic problems such as low entrepreneurial activity, pressure on local services and infrastructure, specialisation on minerals and unaffordable housing [32, 35, 64], resource dependence of the economy which may lead to the crowding out of other sectors, instability and insecurity due to the dependence on the fluctuating external demand [32] and possible slower national economic growth [65].

3.2 Social value capture

Some of the potential factors related to the social gain from resource related activities include better education [49], a reduction in poverty [66], improved communication access [49], an increase in disease prevention initiatives [67], improved income levels [1, 22, 32, 49], lower unemployment [48] and a more equitable distribution of income [1]. Some of the social problems that have been associated with resources related activities include conflict [21, 65, 68], corruption [65, 69], the displacement and relocation of communities [21, 70, 71], the disruption of traditional cultures [72], risks to human health such as deaths through contamination, mine injuries, the increased spread of sexually transmitted diseases, mental health issues, addiction, family stress, increased violence towards women and the intake of toxins through contaminated water [73-75], the aggravation of societal issues through the white washing effect of corporate social responsibility [72, 76], poor working conditions [35], poorer education [32], inequality [65], rentier states [65], stranded regions [32] and human rights suppression [75].

3.3 Environmental value capture

As far as minerals and the environment is concerned, the focus in literature and elsewhere is generally on minimising the negative impacts on the environment. However, positive impacts such as man-made habitats for protected birds have been reported [77]. Some of the reported negative effects include deforestation [35], degraded recreational resources [78], general environmental degradation [35, 69, 75], erosion [35, 78], the loss of fauna [72], the loss of habitats for fauna [78], the introduction of non-native species [78], the pollution and contamination of the environment leading to air quality degradation [11, 73], ecosystem degradation [73, 78] and heavy metal contamination [75], toxic spills [75], risks to clean water supplies [11, 35, 78] and visual degradation [11]. There has also been an increasing trend towards the cumulative assessment of impacts as to not view impacts in isolation [11, 75, 79, 80].

4. FACTORS INFLUENCING THE SHAPE OF MINERAL VALUE CHAINS

The factors that influence the location of mineral processing activities and thus the shape of mineral value chains can be conceptualised as enabling and constraining factors that influence the context for stakeholder decisions that ultimately determine the shape of mineral value chains. These decisions again impact on the enabling and constraining factors. This is illustrated in Figure 3.

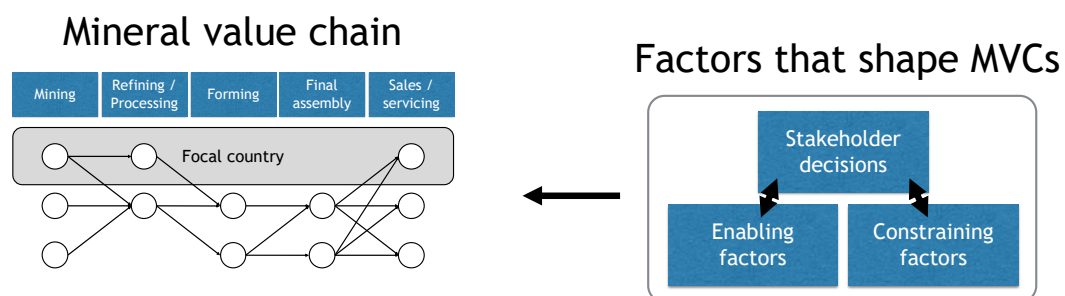


Figure 3: Factors influencing the shape of mineral value chains.

The enabling factors identified include access to capital [30, 53], expectation of sustained demand [81, 82], clusters and corridors [11, 29], sizeable domestic markets [57], improved technology and processing techniques [30, 53, 83, 84], infrastructure [30, 81], local suppliers [29, 38], competitiveness supported by labour productivity, management practices and quality ore [85], supportive policies [29, 30, 38, 70], continued research



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and development [33, 60, 86], the regulation and formalisation of industries [21], local skills [30], subsidies [10], tax breaks [1, 21] and trust [38].

The constraining factors identified in the literature review include demand and price volatility [32, 87], competition [32, 81], environmental concerns [83], exhaustion of resources [32], increased cost of production [32], land acquisition difficulty [53], a restrictive and uncertain legislative environment [82, 88, 89], logistical costs [47], physical infrastructure [29, 57], a decrease in investor confidence brought on by resource nationalism [1], substance restrictions [39], supplier readiness [38] and the availability of water [83].

In the environment of the enabling and constraining factors at a given time, different stakeholders make decisions that impact the shape of the mineral value chain. These include end-users making product choices determined by a variety of factors. These may also include their perceptions on the sustainability of the products that they are buying [39].

Governments also influence the shape of mineral value chains through policy stances, which may vary from neoliberal to resource nationalistic [90] and may directly interfere through, for example, the nationalisation of mines or the protection of specific industries [3, 91, 92]. Company decisions also influence the shape of mineral value chains through supplier decisions and procurement policies [38, 39]. Other influencing stakeholders may include employees, NGOs and local communities [21].

5. FACTORS INFLUENCING THE VALUE CAPTURE FROM MINERAL VALUE CHAINS

Similar to the impact drivers suggested by Franks et al. [11], this section presents a conceptualisation of the value capture from mineral value chains as being determined primarily by the actions of productive actors within the context created by government and other stakeholders as illustrated in Figure 4.

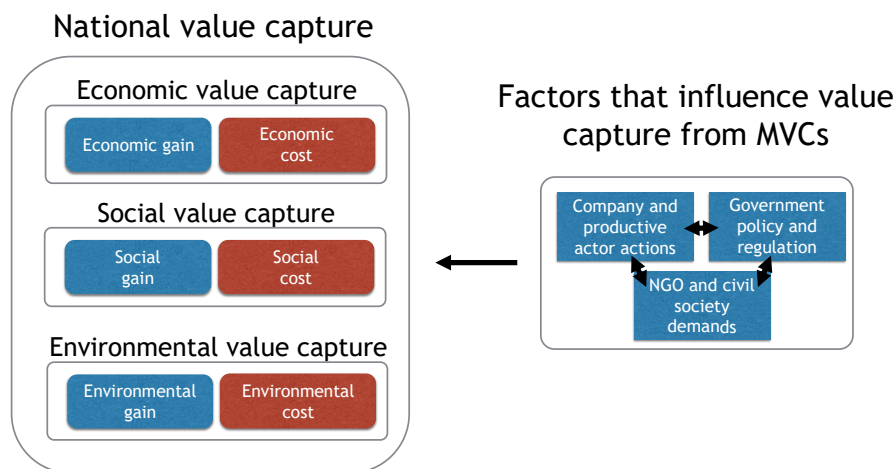


Figure 4: An illustration of the factors influencing the value capture from mineral value chains.

The actions of companies and other individuals and entities involved in productive activities play a predominant role in the value capture outcomes of mineral related activities [7, 11, 72, 90, 93]. These actions may be influenced by the boundaries set by government [11, 28, 36, 70, 73, 89, 90, 94- 101], the business model and values of the companies or individuals involved in productive activities [93], NGO's [21] or civil society and local communities [11, 90, 99].

These non-productive actors fulfil a crucial role by influencing the actions of government and those involved in productive activities. This goes some way in explaining the increasing emphasis in literature on the so called "social licenses to operate" [96, 102-115] and multi-stakeholder forums and collaboration to achieve better outcomes for all the stakeholders involved [72, 80, 103, 116].

6. COLLATED CONCEPTUAL MODEL

The four conceptual aspects presented in Section 2 through 5 can be collated into a single conceptual model, as shown in Figure 5.

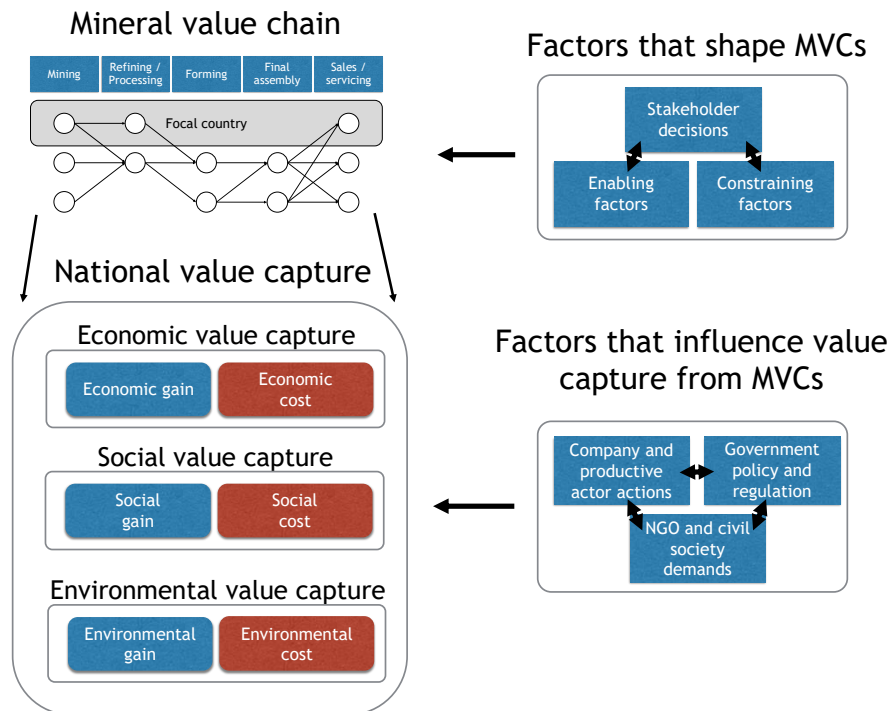
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Figure 5: Collated mineral value chain value capture conceptual model.

The proposed model is a major simplification of all the dynamics at play. In particular, there may be factors that influence the shape of MVCs and the value capture from them. For example, a policy of higher mineral taxation may increase the short to medium term income from minerals for the country, but may lead to less investment in the host nations over the medium to longer term.

The model also does not explicitly account for feedback loops that may exist in the system. For example, the level of national value capture achieved from minerals may influence the expectations and demands of civil society, which may, in turn, influence how they interact with other stakeholders to influence the national value capture.

By simplifying the dynamics at play the model aims to provide a starting point for mineral policy discussions that ensure a sustainable development agenda and a best practice perspective. It also serves to support an appreciation of the important roles of different role players in the MVCs within host countries. This is achieved by providing a clearer conceptualisation of how policies might impact the local footprint of and national value capture from mineral resource value chains.

7. CONCLUSION

This paper aimed to address the need for a conceptual model by which policy makers can conceptualise the shape and impact of mineral value chains and how their decisions influence the shape of and value capture from mineral value chains. The model combines a high level value chain perspective with the triple bottom line dimensions of sustainable development. From this dual perspective, the conceptual model was inductively constructed by reviewing 304 articles published in the journal *Resources Policy* since the start of 2010 up until the 12th July 2015. Instead of delivering the final word, the proposed model aims to stimulate increased discourse surrounding a more holistic view of value capture from mineral value chains, particularly for mineral rich countries and to provide policy makers with a starting point from which to consider their mineral related policies.

The first element of the conceptual model focuses on the elements of a mineral value chain. Although various possible dimensions are identified, the proposed conceptualisation focusses on the producer-consumer dimension of the value chain. The second element of the conceptual model is the national value capture from mineral value chains. It explores the positive and negative value capture aspects of the economic, social and environmental



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sustainability dimensions from mineral related activities identified in the literature review. The third element of the conceptual model focuses on the factors that influence the shape of the mineral value chain. It explores the role of stakeholders decisions and how these are influenced by local and global enabling and constraining factors. The final element of the model focuses on the factors that influence the value capture from mineral value chains. It emphasises the role of productive actors in bringing about the different aspects of local value capture, while illuminating the role of government and civil society to influence the actions of these productive actors.

The proposed model captures the current thinking on mineral value chains and how they translate to value for host nations. The model also highlights the tensions between ensuring a greater local value chain footprint, while ensuring a more positive value attainment from this footprint.

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2.3 Conclusion: Chapter 2

The article presented in Section 2.2 considers how to contextualise and conceptualise beneficiation to reduce the assumptions made with respect to its merits and drivers and to position it within the broader context of economic development within a country. The emerging framework provides a perspective on how mineral value chains and the value capture derived from them may be conceptualised. The framework highlights the distinction between where activities take place and the value capture that may be obtained from them. It also highlights the factors that affect both the location of mineral extraction related activities and the value capture from these activities.

In terms of where beneficiation takes place, the conceptualisation raises two fundamental questions that are key to providing better guidance in terms of beneficiation policy. These are: i) how strategically valuable are particular processing activities in terms of the value capture that could be derived from them?; and ii) could the mineral producing country attain this activity (if it is deemed to be strategic) and, if so, how might it be able to do so? The first question relates to whether the activity contributes to the economic, social or environmental objective(s) of a mineral producing country. The second question relates to the drivers of the location of the activity and the cost and feasibility of intervening to alter the outcomes of these drivers. Only when both these questions are considered in tandem, can a decision be made regarding whether a country's government should intervene to attempt to attain a particular mineral processing activity or not.

Feedback from the peer-review of the article presented in Section 2.2 highlighted the opportunity to further contextualise the proposed framework in the existing global value chain (GVC) literature. Appendix A thus explores how the key concepts from this chapter (namely the assessment of both positive and negative value capture from activities) could be integrated into the existing GVC analysis frameworks.

Chapter 3

Comparing publicly available sustainability disclosures

This chapter is the first of three chapters that aim to address the second objective of this research, namely to “develop new/adapted analytical frameworks that provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities”. This chapter and the following chapter (Chapter 4) form a unit addressing the use of publicly available sustainability disclosures for supporting the identification of developmental sectors with high strategic value. This chapter consists of three sections. Section 3.1 situates the chapter within the narrative of the dissertation (as summarised in Figure 3.1). Section 3.2 contains the article which comprises the primary part of this chapter. Finally, Section 3.3 concludes the chapter by summarising its contribution to the dissertation.

3.1 Introduction: Chapter 3

In Chapter 1 it is argued that little guidance exists in the beneficiation literature in terms of determining the strategic value of particular processing activities. Consequently, this research turned to the literature regarding the determination of the strategic value of developmental industries in general. However, there was also found to be limited guidance in this field regarding how the strategic value of industries should be assessed apart from the use of detailed ad-hoc feasibility studies. Hence, novel approaches were explored in order to address this gap. The first promising approach that was further explored was the use of public sustainability disclosures. Given the rise of the use of these disclosures and their inclusion of all three dimensions of the triple bottom line, it was investigated whether they might be able to provide insights regarding the developmental potential of industries. In order to test this approach to establishing the developmental potential of industries, it was first necessary to assess the available public sustainability disclosure frameworks

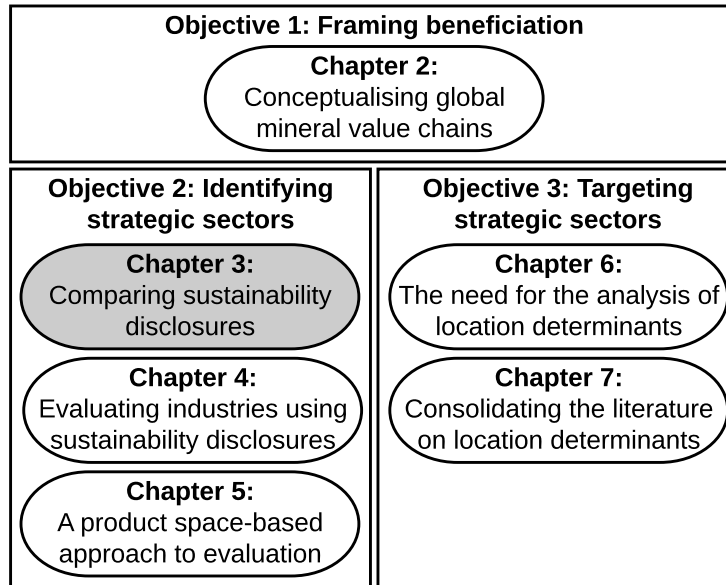


Figure 3.1: Position of Chapter 3 in dissertation.

in terms of their suitability for this purpose. This chapter thus outlines how an industry evaluation framework based on public sustainability disclosures might be constructed and evaluates different sustainability disclosures frameworks to determine their suitability to act as foundation for such an evaluation framework.

3.2 Article: “Scoping phase comparison of development opportunities by making use of publicly available sustainability information”

The article presented in this section is the published version of a peer-reviewed article published in *Procedia Manufacturing* as part of the proceedings of the 14th Global Conference on Sustainable Manufacturing (GCSM) that was held in Stellenbosch in 2016. The international conference provided the ideal opportunity for the candidate to expose the framework to peer-review and the linked conference provided the opportunity for the candidate to engage with and get feedback from the international research community interested in sustainability related research. The financial assistance of the National Research Foundation (NRF) and Anglo American is gratefully acknowledged. Opinions expressed and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the NRF or Anglo American. The online version of the article is available at <https://doi.org/10.1016/j.promfg.2017.02.026>.



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Scoping phase comparison of development opportunities by making use of publicly available sustainability information

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Abstract

With sustainable business strategies and sustainability reporting now a norm, the public domain has in recent years been flooded with sustainable development information from a wide range of organizations. Although this information is generally retrospective in nature, an opportunity exists to make use of this information to compare the impact of different development opportunities prospectively, based on the performance of similar industries elsewhere. This paper therefore evaluates the potential of using publicly available sustainability information to enhance scoping phase decision-making by policymakers in order to prioritize projects that have the most potential for creating sustainable outcomes. The paper outlines a concept model for using sustainability information to compare development opportunities, followed by an analysis of five prominent international sustainability reporting frameworks at the hand of specific criteria to establish which framework would be most suitable to serve as basis for such a model.

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Keywords: Sustainability; Feasibility studies; Scoping; Global Reporting Initiative; Sustainable Development; Industrial development

1. Introduction

Policymakers are often faced with the difficult decision of where to focus limited resources regarding the development of new industries in countries where such industries are lacking. Such decisions are further complicated by the demands of sustainable development which necessitate the assessment of development potential not only in terms of economic aspects, but also taking the social- and environmental aspects into account.

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It is therefore not surprising that feasibility studies are recognized to be an important part of the pre-investment phase of development projects [1]. Due to the considerable complexity of aspects to be taken into account and the substantial amount of time, effort and funding typically involved in feasibility studies, the feasibility study process has evolved to a point where it is generally an iterative, multiphase process. Feasibility studies generally consist of three phases, namely the conceptual or scoping phase, followed by the preliminary or prefeasibility phase and concluded by the final or definitive phase. The focus of the feasibility study narrows and the resources invested as well as the value created by the study increases with each consecutive phase [2].

The scoping phase is of particular relevance to the present investigation. Being the first stage in the feasibility assessment process, the scoping phase generally aims to “define the potential of a project, eliminate those options that are unlikely to become optimal, and determine if there is sufficient opportunity to justify the investment required for further studies” [3]. It is therefore desirable that the scoping phase be concluded quickly and without considerable resource investment, yet reaches an accurate and transparent conclusion as to which opportunities hold the most potential for sustainable growth. Benefit measurement modeling approaches, including comparative models, scoring approaches, traditional economic models and group decision techniques [4], are typically used to reach such conclusions. However, the use of such models are laborious, time consuming and expensive [5], often as a result of the data requirements of these models [4]. These methods can therefore not be readily used in the scoping phase and typically only form part of latter, more detailed feasibility studies.

Sustainable business strategies and sustainability reporting has become a norm in recent years [6] and, subsequently, the public domain has been flooded with sustainable development information from a wide range of organizations, from almost all industries. This has produced an opportunity to develop models that make use of this easily accessible information to assess the feasibility and potential impact of different development opportunities, based on the performance of similar industries elsewhere. This may be especially useful if a model can be developed that makes use of sustainability information as presented in sustainability reports, thereby greatly simplifying and speeding up the process of data collection. Although many different sustainability reporting frameworks and guidelines are used in the preparation of sustainability reports, some prominent international frameworks, such as the Global Reporting Initiative (GRI) G4 Reporting Framework, are very widely used. It is therefore sensible to develop a model that makes use of the information disclosed according to the guidelines provided by such prominent frameworks.

A model of this kind would typically be useful in the scoping phase of the feasibility assessment process, as the aim of such a model is the rapid evaluation of different development opportunities and the conclusions may therefore not necessarily exhibit a sufficiently high level of accuracy as required for detailed feasibility assessments.

This paper ultimately aims to evaluate the potential of using organizational sustainability information available in the public domain to enhance the efficiency of scoping phase decision-making by policymakers in order to rapidly prioritize projects that are most likely to produce better sustainability outcomes. This paper therefore starts by discussing a concept structure for a model that makes use of sustainability data typically reported in sustainability reports. Requirements for the framework on which such a model can be based are then outlined. Finally, five prominent international sustainability reporting frameworks are analysed in terms of the previously defined requirements in order to identify those most suitable to serve as basis for the development of the abovementioned model.

2. Concept model structure

Sustainable development has traditionally been defined in terms of the Triple Bottom Line (TBL), a term coined by Elkington in 1994, referring to the equal importance of economic-, environmental- and social value creation in an organization [7]. It is therefore not surprising that with the advent of sustainability reporting and the subsequent development of some of the most prominent sustainability reporting frameworks, the triple bottom line was used as foundation [8]. Some more recent frameworks, like the International Integrated Reporting Council's (IIRC) Integrated Reporting (<IR>) Framework, is based on the concept that sustainable development progress can be measured in terms

of value creation in six capitals within an organization, namely financial-, manufactured-, intellectual-, social and relationship-, human-, and natural capital [9].

Irrespective of the dimensions in which sustainable development progress is measured, most sustainability reporting frameworks define a number of aspects in these dimensions that have to be measured and reported periodically in order to track sustainable development progress. Many frameworks further also define specific indicators to be used to measure progress in terms of these aspects, for example the GRI G4 Sustainability Reporting Guidelines [10], although some frameworks, like the IIRC <IR> Framework, favor the flexibility of not defining specific indicators that have to be applied by all organizations [9].

The requirement that all aspects of sustainable development be taken into account, coupled with the complexity of aspects to be measured, means most frameworks make use of a fairly large number of indicators. Most often, the usefulness of these indicators for decision-making purposes is limited by the inability of the user to draw an objective conclusion by considering all the individual indicators and their interrelationships [11]. As a result, the potential usefulness of a model that captures the essence of all the individual indicators and produces one or a few indices on which decisions can be based is widely discussed in literature [11, 12, 13, 14]. It is therefore deemed unnecessary to discuss the details of development of such a model in this paper; rather the potential use of such a model is elucidated briefly.

It is envisaged that the model will aggregate the indicators reported according to the guidelines of a reporting framework into composite indices – an index for each dimension of sustainable development as defined by the relevant framework. Figure 1 illustrates the comparison of development opportunities by considering three composite indices based on the triple bottom line definition of sustainability. As individual sustainability indicators are aggregated to form a composite index for each dimension, the results are transparent and easily analysable to establish which specific indicators contribute significantly to the difference in index values. This enhances the ability of the decision-maker to

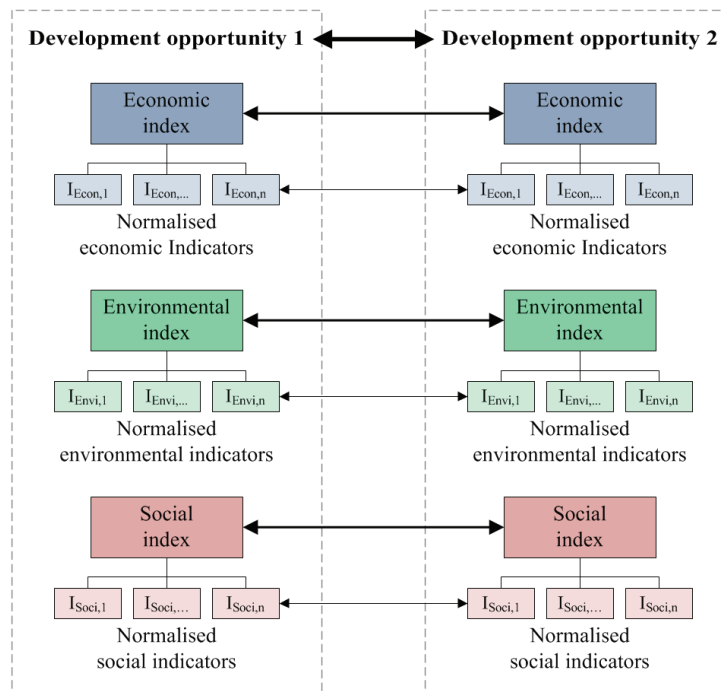


Fig. 1. Comparison of development opportunities by comparison of indices

apply his/her own discretion as to how the differences in the values of the composite indices should be interpreted and increases the credibility of decisions made based on the comparison of the indices.

The structure of the framework on which the model is based has to meet some requirements in order to produce meaningful results.

3. Framework requirements

The criteria to be met in order for a framework to be usable as basis for the model discussed in the previous section will now be discussed briefly. It is assumed that the abovementioned model will only be based on recognized frameworks which include requirements to ensure high quality information is ultimately disclosed by following the framework guidelines. As such, these requirements regarding the quality of the disclosed information is not part of the criteria for eligibility of frameworks discussed in this section. Although all the criteria discussed in this section are important, they are not all of equal importance. The perceived importance of each criterion is therefore also discussed shortly.

3.1. Temporal orientation

The assessment of development opportunities is prospective in nature. It is thus of value if a framework requires disclosure of prospective information. Retrospective information have to be adjusted for inter alia, inflation, exchange rate changes, changes in the industry and growth factors when assessing prospective opportunities and these adjustments may introduce some inaccuracy in the data. However, as the proposed model is aimed at the rapid completion of scoping phase comparison of opportunities, the inaccuracies introduced by such adjustments may be acceptable if limited as far as possible. A prospective temporal dimension is therefore deemed favourable, but not a requirement.

3.2. Nature of indicators

In order to allow comparison of different potential industries that can be developed, the same indicators have to be used for all industries. It is therefore important that standardized indicators are used to disclose information. Although some frameworks, notably the IIRC <IR> Framework, do not prescribe the use of specific indicators for disclosure quality reasons, comparison of narrative-based- or non-standardized indicator information is tedious and problematic. Therefore, for the present investigation, standardized indicators were deemed to be more favourable. Further, it is widely noted in literature that integrated indicators (accounting for the interrelationships between the different dimensions of sustainability) are required for the accurate measurement of sustainable development progress [15, 16, 17]. This does not invalidate the use of non-integrated indicators, but a balance between both is recommended [9]. Therefore, frameworks that include integrated indicators were deemed to be more favourable.

3.3. Scope of indicators

Although the majority of sustainability assessment frameworks define requirements for indicators to ensure sufficient disclosure of the intended sustainability information, all frameworks do not necessarily include indicators that cover all three dimensions of sustainability i.e. environmental, social and economic. With regard to the present investigation, it is important to assess development opportunities in terms of all the dimensions of sustainability. No conclusion can be reached regarding the feasibility of a development opportunity if its potential impact on all the dimensions of sustainability is not taken into account. As such, frameworks that do not consider all the dimensions of sustainability are not considered to be sufficient for the purposes of the present investigation.

3.4. Level of assessment

As mentioned in the introduction of this paper, the present investigation aims to evaluate the potential of using sustainability information available in the public domain to enhance decision-making by policymakers regarding different development opportunities. As such, the intended assessment will be done at industry level – considering the potential for establishing an industry, not only a single organization. Therefore, it will be advantageous if a framework intended for industry-level assessment can be used. However, sustainability- and integrated reporting are generally conducted at organization-level and, as a result, most sustainability assessment frameworks are developed for organization-level assessment. It is therefore likely that organization-level information will have to be scaled in order to represent industry-wide data.

3.5. Usage

Widely used frameworks are favoured as widespread use of a framework by organizations operating under different circumstances (political, geographical etc.) and in different industries increases the probability of finding representative information and allows one to consider similar industries operating under different circumstances, thereby ensuring appropriate information is used. Further, widespread use of a framework also implies that the framework is deemed acceptable and sufficient by many users, increasing the credibility of information attained from or based on that framework. It is acknowledged that in some cases less widely used frameworks may be appropriate and therefore widespread use of a framework is favourable, but is not deemed to be a requirement.

3.6. Data disclosure

As discussed in section 2, a notable strength of the proposed model structure is the fact that indices can be analysed to ascertain which individual indicators result in one opportunity being superior or inferior relative to another. This allows the decision maker to allow for certain trade-offs depending on the requirements and priorities of a given development initiative. The availability of disaggregated information is therefore very important and frameworks which only require disclosure of aggregated information are therefore deemed insufficient for the present investigation.

4. Analysis of reporting frameworks

With the ever-increasing global emphasis on sustainable business strategies and sustainability reporting, a host of sustainability reporting frameworks have been developed over the past two decades. These frameworks generally aim to standardize transparent and comprehensive sustainability reporting at national, regional or international level.

Reporting frameworks developed with the aim of international implementation are particularly relevant to the present investigation due to the potential larger range of industries and organizations that can make use of these frameworks to disclose sustainability information. Some sector specific frameworks may meet the criteria outlined above, however, this paper specifically focuses on generic frameworks and as such, sector specific frameworks are not included in the analysis.

Five prominent international reporting frameworks were analysed in this section, namely the GRI G4 Sustainability Reporting Guidelines [10], the CDP environmental information requests [11], the IIRC's <IR> Framework [12], the Sustainability Accounting Standards Board (SASB) standards [13] as well as the United Nations Global Compact (UNGC) Communication of Progress (COP) guidelines [14]. These frameworks are well known globally and the background and underlying principles of each are therefore not discussed in this paper. Table 1 summarizes the characteristics of these frameworks at the hand of the criteria outlined in section 3.

Although these frameworks are all sufficient in fulfilling the respective intended purposes, the criteria outlined in section 3 have to be considered to establish whether these frameworks are suitable to be used as basis for development

of the proposed model. This section therefore presents a brief analysis of the abovementioned frameworks at the hand of the criteria discussed in section 3.

Table 1. Summary of framework characteristics

	GRI G4 Sustainability Reporting Guidelines	CDP environmental information requests	IIRC Integrated Reporting Framework	Sustainability Accounting Standards Board	UNGC Communication on Progress
Temporal orientation	Predominantly retrospective	Retrospective & Prospective	Retrospective & Prospective	Predominantly retrospective	Retrospective & Prospective
Nature of indicators	Standardised	Standardised	Non-standardised	Standardised	Standardised
Scope of indicators	Non-integrated	Non-integrated	Integrated	Non-integrated	Non-integrated
Level of assessment	Comprehensive	Limited	Variable	Limited	Limited
Usage	Organisation level	Organisation level	Organisation level	Organisation level	Organisation level
Data disclosure	Almost universal	Widespread	Increasingly widespread	Increasingly widespread	Limited
Key:	Open access	Open access	Open access	Open access	Open access
Key:	Ideal characteristic	Acceptable characteristic	Unfavourable characteristic		

In Table 1 it can be noted that none of the frameworks match all the ideal criteria outlined in the previous section. This might be expected as the present study makes use of information from the frameworks differently than the originally intended primary functions of the frameworks. The fact that none of the frameworks are ideal for the present purpose does not necessarily disqualify their use, but, importantly, it does indicate that making use of these frameworks might require some manipulation, with specific assumptions and scaling of data likely necessary.

As captured in Table 1, the GRI G4 guidelines and the SASB standards are strongly focused on retrospective reporting of performance, with little or no use of prospective indicators (targets, planned developments), and the temporal dimension of these frameworks are therefore deemed unfavourable. Further, although the IIRC <IR> Framework is the only framework that encourages integrated thinking, it does not make use of standardised indicators used by all reporting organisations. The scope of indicators reported in the CDP environmental information requests, SASB standards and UNGC COP is limited and does not cover all three dimensions of sustainability, which is very unfavourable for the purpose investigated here. The widespread use of the GRI guidelines and the CDP environmental information requests (78% of companies that publish corporate responsibility reports make use of the GRI guidelines [6] and CDP has gathered “the largest global collection of self-reported environmental information” [11]) are favourable, although the use of the IIRC <IR> Framework and SASB standards is also increasing. Finally, all the frameworks evaluated here are focused on organisation-level reporting (unfavourable), but all require the complete disclosure of disaggregated information (favourable).

Based on the assessment criteria, the GRI G4 Sustainability Reporting Guidelines are the most appropriate framework to be used as it fulfils the most of the characteristic requirements out of all the frameworks compared (4 ideal characteristics out of 7), although it has been criticized for its lack of integrated indicators [9]. This is followed closely by the CDP environmental information requests (3 ideal characteristics and 1 acceptable characteristic out of 7) and IIRC <IR> Framework (2 ideal characteristics and 3 acceptable characteristics out of 7). The primary problem of using the CDP information requests is the fact that these requests do not include financial or social disclosures. This means that the CDP information requests cannot be used as the sole source of sustainability information and would have to be used complementary to another framework in which financial and social disclosures are made. Although the IIRC <IR> Framework does require disclosure on all the aspects of sustainability, it does not specify the indicators

to be used for such disclosure. The indicators used by different organizations to report on a specific aspect are therefore likely to differ, making direct comparison difficult. However, the IIRC <IR> Framework does emphasize the importance of integrated thinking, an aspect that is lacking in the GRI G4 guidelines. Taking all these factors into consideration, it is the widespread use of the GRI G4 guidelines that presently makes it preferable above the IIRC <IR> Framework for the purposes of this study. However, with increasing use of the IIRC <IR> Framework expected globally, this may change in the near future.

Based on the results in Table 1, the SASB standards and the UNGC COP are less suited for the present purpose than the GRI G4 guidelines, CDP information requests and the IIRC <IR> Framework. This is primarily a result of the limited number of indicators that the SASB standards and UNGC COP require to be disclosed. Although the SASB limits the number of indicators to be used on purpose (based on a materiality assessment), this is not preferable for the purpose investigated in the present study. The SASB standards require disclosure of different indicators for different industries, which can further vary within an industry based on the individual materiality assessments of organizations. Therefore, comparability of different industries, as is required in the present investigation, is inherently difficult when using the SASB standards. Regarding the UNGC COP, the ten principles on which disclosures are based are not comprehensive and do not require quantitative information. The UNGC therefore recommends that organizations seeking to disclose sustainability progress more comprehensively to make use of the GRI G4 reporting framework. A collaborative document by the GRI and the UNGC that outline the complementary nature of these initiatives is available to guide this process [15].

5. Conclusions

A potential opportunity is identified to make use of the increasing amount of organizational sustainability information available in the public domain to enhance the efficiency of scoping phase decision-making by policymakers such that projects that are most likely to produce sustainable outcomes are prioritized rapidly. To this end, a concept model that makes use of sustainability indicators was introduced, as well as criteria that have to be considered when choosing a sustainability indicator framework on which such a model can be based. Five prominent indicator frameworks were subsequently analysed according to these criteria. It was found that none of the frameworks match all the ideal criteria, but it was concluded that the GRI G4 Sustainability Reporting Guidelines is the most suitable to be used as basis for a model facilitating the high level comparison of different development opportunities. Although the GRI G4 framework requires predominantly retrospective information to be disclosed and has been criticized for its use of non-integrated indicators, these problems are not substantial enough to disqualify its use. The IIRC <IR> Framework was deemed to be only slightly less suited than the GRI G4 guidelines due to its lack of standardized indicators (making comparison difficult) and slightly less widespread use. Although the CDP information requests did not compare poorly to the GRI G4 guidelines for the purpose investigated here, the use of the information requests was disqualified as it only considered environmental information.

Finally, it can be concluded that making use of publicly available sustainability information reported according to prominent international sustainability reporting frameworks to enhance scoping phase decision-making may indeed be possible. It is recommended that a model that makes use of publicly available sustainability information as discussed in this paper be developed and validated in order to prove the possible utility and potential shortcomings of using such a model in the early stages of policy related decision-making. In such a model the emphasis would be on ease of use, perhaps even allowing for the potential that, with increasing standardization of reported data, automatic data collection and analysis might become possible in the future. The limitations of such a model, including the generalization of impacts of specific industries over geographical and political boundaries and the extrapolation of retrospective data to assess opportunities prospectively, should be minimized throughout development and use of such a model.

Acknowledgements

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3.3 Conclusion: Chapter 3

Given the rise of the use of corporate sustainability disclosures, it was investigated whether they might be able to provide insights regarding the developmental potential of industries. In order to test this approach to establishing the developmental potential of industries, it was first necessary to assess the available public sustainability disclosure frameworks in terms of their suitability for this purpose. Section 3.2 thus outlines how an industry evaluation framework based on public sustainability disclosures might be constructed and evaluates different sustainability disclosures frameworks to determine their suitability to act as foundation for such an evaluation framework. Based on this assessment, the GRI G4 framework was identified as the most suitable for the purposes of this research. The following chapter (Chapter 4) thus utilises the GRI G4 framework as a foundation to construct and test the use of a disclosures-based framework for the assessment of the developmental potential of industries.

Chapter 4

Evaluating the developmental potential of industries using sustainability disclosures

This chapter is the second of three chapters that aim to address the second objective of this research, namely to “develop new/adapted analytical frameworks that provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities”. This chapter and the previous chapter (Chapter 3) form a unit addressing the use of publicly available sustainability disclosures for supporting the identification of developmental sectors with high strategic value. This chapter consists of three sections. Section 4.1 situates the chapter within the narrative of the dissertation (as summarised in Figure 4.1). Section 4.2 contains the article which comprises the primary part of this chapter. Finally, Section 4.3 concludes the chapter by summarising its contribution to the dissertation.

4.1 Introduction: Chapter 4

This chapter builds on the previous chapter (Chapter 3) where the leading sustainability disclosure frameworks were evaluated for their potential to be leveraged to support the evaluation of development sectors. This chapter explores the use of the GRI G4 sustainability reporting guidelines (identified in the previous chapter as holding particular promise) as a foundation for such a framework. The industry evaluation framework based on the GRI G4 framework is tested on the case of platinum beneficiation in South Africa. Reflecting on the results, it is suggested that despite clearly being useful, the framework’s potential is still hampered by the constraints inherent in the data being used (e.g. that data is only available for existing companies, that the data may not be available at the product level and that the data may be biased due to various reasons). It is envisioned that some of these constraints may be overcome

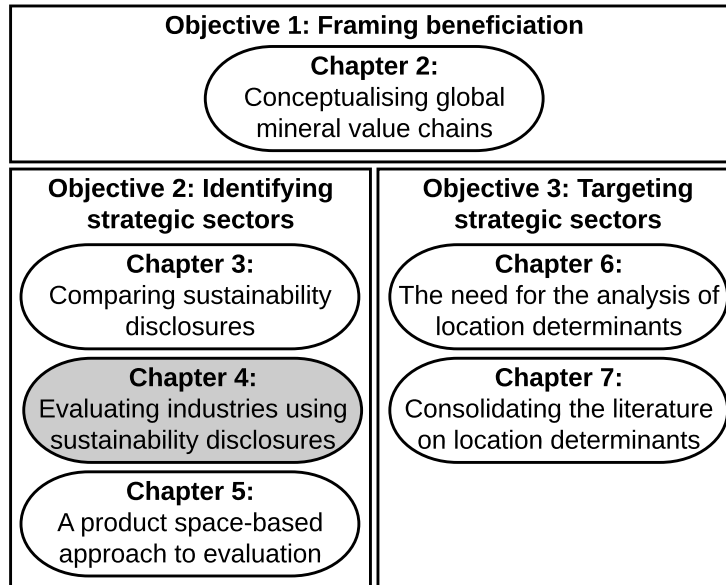


Figure 4.1: Position of Chapter 4 in dissertation.

as sustainability disclosures continue to be improved in future.


4.2 Article: “Comparing the Sustainable Development Potential of Industries: A Role for Sustainability Disclosures?”

The article presented in this section is the published version of a peer-reviewed article published in the international open-access journal *Sustainability*. The contribution of Stellenbosch University’s Open Access Publication Fund toward the article processing fee is gratefully acknowledged, as is the financial assistance of the National Research Foundation (NRF) and Anglo American. Opinions expressed and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the NRF or Anglo American. The online version of the article is available at <https://doi.org/10.3390/su10030878>.



Article

Comparing the Sustainable Development Potential of Industries: A Role for Sustainability Disclosures?

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Abstract: Governments often seek to facilitate sustainable growth through the targeted support of specific industries that are deemed to have considerable sustainable development potential. However, the selection of appropriate sectors generally relies on resource-intensive assessment processes. With the recent flood of sustainability information into the public domain, there appears to exist an opportunity to use this information to improve the efficiency of the initial stages of evaluating target industries. This work investigated the development of a framework that makes use of public sustainability disclosures to rapidly compare industries in terms of their sustainable development potential. The goal was to evaluate whether such a framework could usefully provide a way to prioritize the execution of more in-depth feasibility studies on industries showing superior sustainable development potential. The developed framework was based on the Global Reporting Initiative's G4 Sustainability Reporting Guidelines and makes use of 18 indicators to compare industries in terms of various triple bottom line considerations. The framework was applied to a case study of the platinum industry in South Africa to establish its usefulness, potential and limitations. The framework facilitated a reasonably holistic, transparent and easily interpretable comparison of industries. However, its consideration of industry fit in the local economy, expected development trends and quantification of indirect economic impacts were found to be areas that could be improved. Some of these concerns might be overcome by the improved availability of public information in the future.

Keywords: sustainability; global reporting initiative; framework; sustainable development; industrial development; feasibility studies

1. Introduction

Governments often seek to spur local development through targeted support of specific parts of the economy that are deemed to have high developmental potential. Such endeavors may find expression in national development strategies that identify target sectors, industries or value chains. These strategies usually involve the promotion of investment in the identified areas, generally facilitated by a government-mandated investment promotion agency (IPA) [1]. IPAs are receiving increasing attention in the global policy realm as governments seize upon the positive correlation between investment promotion and increased foreign direct investment (FDI) [2,3].

The target sectors, industries or value chains need to be selected such that they align with the government's strategic goals and provide the best possible outcomes for a given investment. Due to the complexity and enormous number of considerations to be taken into account when considering an investment decision, an iterative, multiphase feasibility assessment process is typically applicable. Such a process involves the collection and examination of information on each alternative to sequentially narrow down the options until the final alternative(s) can be selected. The resources invested and, as a

result, the information available on each alternative, as well as the value created by such assessments typically increase with each consecutive phase, while the focus simultaneously narrows. Due to the iterative and multiphase nature of this process, a substantial amount of resources—time, effort and funding—is generally invested in the feasibility assessment process [4,5]. This has been exacerbated by the evolution of justifying investment decisions from being primarily based on maximizing economic value creation to systematically considering environmental and social factors as well [6,7].

Policymakers often depend on tools and instruments, such as indicator frameworks, to rapidly identify the most appropriate targets for investment promotion to maximize the return on investment [8]. All of these tools, and any feasibility assessment study, rely on the reliable collection of data. It therefore follows that simplifying and/or shortening the data collection process may result in substantial savings in terms of resources invested in the study.

One opportunity to improve the efficiency of gathering data for feasibility studies, may lie in the recent flood of sustainability information into the public domain. This information is a result of the ever-increasing global emphasis on sustainable business strategies and corporate social responsibility, with corporate sustainability reporting subsequently becoming a global norm [9]. An opportunity exists to make use of this sustainability information in a structured (and even automated) manner to support the improved and rapid decision-making regarding investment in the development of new industries during the initial stages of investment feasibility studies [10]. This has the potential to dramatically reduce the time required for such studies and to greatly improve the information available to entities like IPAs for comparing different development opportunities in the early stages of selecting target sectors. This may be particularly pertinent for developing countries, where the resources available for undertaking such feasibility studies may be even more constrained.

This exploratory study therefore aimed to evaluate the potential of using publicly available sustainability information for comparing different development opportunities in terms of the Triple Bottom Line (TBL) [11]. This was accomplished by developing a feasibility comparison framework that uses well-known sustainability indicators to facilitate the rapid, high level comparison of potential development opportunities, as would typically be useful during the initial stages of identifying viable industries for development in the local economy. This framework was then tested by applying it to a case study on the platinum industry in South Africa to establish its usefulness, potential and limitations.

The paper emphasizes the positive change that can potentially be attained by creatively using the growing amount of sustainability information in the public domain. Simply disclosing sustainability information will not affect change. The academic community thus plays a critical role in operationalizing sustainable development by developing innovative methods that make use of available information (in this case, sustainability disclosure) to guide decision-making. The rest of this article provides an overview of the related literature (Section 2), outlines the research methodology that was followed (Section 3) and presents the proposed assessment framework (Section 4). The results of the case study are then presented in Section 5, followed by a reflection on the utility, potential and shortcomings of the framework (Section 6) and concluding remarks (Section 7).

2. Literature

This section presents a high-level overview of the fundamental underlying aspects considered in the development of the framework. The section commences with a very brief overview of some notable, recent work on the definition of sustainability assessment (Section 2.1). Section 2.2 then presents an overview of relevant past work in terms of tendencies in sustainability reporting and the use and aggregation of sustainability indicators. This is followed by a discussion of how such indicators, structured into indicator frameworks, may be used for comparing sustainable development potential (Section 2.3).

2.1. Sustainability Assessment

A vast literature exists regarding sustainability assessment and an exhaustive discussion of this literature will therefore not be attempted in this paper. In a very recent paper, Pope et al. [12] acknowledges that due to the rapid expansion of the sustainability assessment practice, the field has become very confusing and they therefore developed a new descriptive conceptual framework for sustainability assessment to aid in the navigation of the field. Bond et al. [13] provides an insightful exposition of what was considered the state of the art of sustainability assessment in 2011. The five aspects that are highlighted for inclusion in sustainability assessments are also considered in the current work. Along the same vein, Gasparatos and Scolobig [14] present a useful overview of the typology of sustainability assessment tools. These authors also present what they found, from literature, to be the five desirable features of sustainability assessment. Although these features differ substantially from the five aspects discussed by Bond et al. [13], they are also explicitly or implicitly included in the work presented in this paper.

2.2. Sustainability Indicators and Aggregation

Sustainability reports are now widely published by companies who seek to voluntarily, or due to local reporting regulations or incentives, disclose information on the sustainability performance of the company. The tendency of companies to publish such reports are influenced by various factors ranging from size and profitability to media exposure and customer proximity. Several studies investigate these tendencies [15–22] with some referring to the legitimacy, stakeholder or agency theories for explanation [17,20,23]. The potential value of such reporting has become increasingly visible, with at least one study finding that sustainability disclosures are valued by investors [18]. It has also been found that such disclosures are positively related to firms' market value. This seems to suggest that leading companies value such disclosures for their ability to signal that they strive to act responsibly [15–21]. Brammer and Pavelin [24] further report that high quality disclosures of environmental information are primarily associated with larger firms and those in sectors related to environmental concerns.

Sustainability indicators, widely used in sustainability reports, aim to reduce the amount of complex interrelationships in our dynamic environment to a manageable amount of meaningful information [25–27]. Each indicator typically considers one or a few specific aspects of sustainable development and have specific inherent advantages and disadvantages to its use. It has therefore become common practice to choose and combine a (often large) number of indicators to measure progress in all the dimensions of sustainable development [25,28].

The usefulness of many individual indicators in decision-making is often limited by the inability of the user to draw an objective and transparent conclusion by considering all the individual indicators. It may therefore be desirable to be able to combine all the indicator values into a single value that captures the essence of all the individual values [29]. The potential value of such aggregated indicators has attracted some research attention and various approaches to aggregate indicators have been proposed [29–33]. The aggregated, single metric thus obtained is commonly referred to as a (composite) sustainability index. Sustainability assessment frameworks often make use of sustainability indicators that are aggregated into indices, to facilitate the quantification of sustainability performance (see, for example, [25,27,28,34]).

Critics warn, however, that the aggregation of indicators can lead to deceptive results due to the inherent subjectivity of the aggregation process [27,35]. Furthermore, Waas et al. [28] note that sustainability indicators and indices are "in every instance a social construction, reduction and simplification of the complex reality and its many uncertainties and risks ...". It is therefore important to follow a process that is as transparent and objective as possible in the development and use of composite indices.

2.3. Comparison of Sustainable Development Potential

In its *“Investment Promotion Handbook for Diplomats”*, the United Nations Conference on Trade and Development (UNCTAD) [1] provides a schematic illustration of the process of identifying sectors and the development and implementation of an investment promotion strategy. This schematic illustration is reproduced in Figure 1. Steps 4–6 in Figure 1 are of particular relevance to the present work. These steps comprise the setting of selection criteria and objectively and transparently assessing the alternatives using these criteria to select the most desirable alternative.

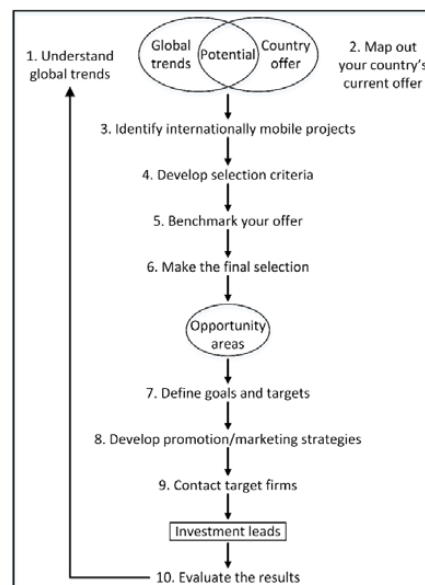


Figure 1. Strategy development and implementation [1].

The UNCTAD developed an indicator framework that addresses steps 4–6 in Figure 1. More specifically, the framework is aimed at informing the process of establishing policy priorities and focusing limited resources on specific sectors, value chains or value chain segments. The framework, however, is focused on maximizing economic value added and job creation from private sector investment, with only a few other sustainable development considerations incorporated. As a result, the framework neglects some aspects of sustainable development and sustainable value creation across all dimensions of the triple bottom line.

Many indicator frameworks aimed at sustainability assessment, which consider the TBL dimensions more comprehensively, can be found in literature. Chen et al. [36] presents a short review and evaluation of tools that can be used for factory sustainability assessment, while Grunda et al. [37] presents an overview of 30 papers published between 1997 and 2010 that focus on organizational sustainability evaluation, assessments and measurement. Table A1 in Appendix A presents a brief summary of some further relevant works that make use of indicators to quantify and assess sustainability.

Further, many approaches have been described that aim to extend analysis beyond simply assessing sustainability and to include the selection of optimal alternatives. Gonzalez et al. [38] introduces 38 works that propose decision-making models and tools to address sustainability challenges in integrative ways. Most of these methods, however, focus on operational-level decisions such as the selection of optimal technologies for improving the energy efficiency of a process [39–41], reducing waste generation [42,43] or enhancing overall sustainability of a process [44–47].

In a work more strongly focused on policy-level assessment, Fitzgerald et al. [48] presents a novel quantitative method that makes use of a list of indicators to evaluate policies aimed at enhancing

urban sustainability. In a work also aimed at policy-level assessment, Greening and Bernow [49] argue strongly for the use of multi-criteria decision-making (MCDM) methods in integrated assessment frameworks to be used to inform the comparison of environmental or energy policy alternatives. Further, some methods have been developed to compare the sustainability of countries or regions. Kouloumpis et al. [50], for example, make use of fuzzy logic to compute the overall sustainability of more than 100 different nations. Similarly, the United Nations Commission on Sustainable Development (UNCSD) [51] developed guidelines for using a set of 58 national indicators to measure countries' progress toward sustainability goals.

From the works mentioned in the preceding paragraphs (and in Table A1), it is clear that sustainability assessment has received substantial research attention. It is also clear that most authors focus on organization- or operation-level assessment of sustainability, with some focusing on a national-level assessment of sustainability. Industry- or sector-level assessments, however, appear to be neglected. Furthermore, industry- or sector-level assessment of sustainability may be especially useful in terms of strategic decision-making by governmental policymakers, such as IPAs, seeking to target specific sectors to be established or further developed in the national economy. Despite this, little literature is available regarding the quantitative comparison and selection of different industries or sectors (by, for example, using a set of predefined indicators, as used for organization-level assessment) to be prioritized in terms of national development policy. This work thus investigates the use of publically available sustainability information collected at the company level, scaled to the industry/sector level to support the sustainability assessment of industries/sectors at a strategic policy level. The following section describes the methodology that was followed to develop a framework that achieves this.

3. Method

The development of the proposed analysis framework followed a methodology consisting of three phases. This section serves to outline these phases and the steps each comprise. The specific structure choices made in each step and the resulting framework are discussed in the following section (Section 4).

Figure 2 illustrates the methodology followed in the development of the framework. Phase 1 served to gain an understanding of literature relevant to the research (as summarized in Section 2). Phase 2, the development of the framework, was based on the approach described in the Handbook on Constructing Composite Indicators [35]. The results of this phase are presented in Section 4. The application of the developed framework to a case study to test its functionality and usability then followed in Phase 3. This results from this case study is presented in Section 5. Based on the outcomes from this methodology, Section 6 provides a discussion of the implications of the results.

Following the literature review conducted in Phase 1, Phase 2 comprised six steps. It started with the selection of an existing reporting framework to serve as basis for the framework developed in the present work. Such a framework serves as the main repository from which well-defined, -structured and -tested indicators were selected, while simultaneously ensuring that indicators are used for which published data are already available. Section 4.2.1 further elaborates in this regard. Following this step, Steps 2.2–2.4 consisted of setting criteria for indicator selection, applying these criteria to the base framework to sieve out indicators that may be superfluous for our purpose and defining the scope and grouping of the selected indicators in the new framework. Sections 4.2.2 and 4.2.3 present more details on the execution of these steps. Having selected and structured the indicators to be used, Step 2.5 then aimed to select the appropriate aggregation scheme in to generate, from the underlying indicators, a single composite index for each dimension of the TBL. Sections 4.2.4 and 4.2.5 discusses the normalization, weighting and aggregation methods used to accomplish this. Phase 2 was concluded with validation of the developed framework by discussion with experts and collection of their inputs regarding the functionality, contribution and usability of the framework in the form of a questionnaire.

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As indicated in Figure 2, these inputs were used to revise the indicators included in the framework, as well as the scope and grouping of the indicators. Section 4.2.6 elaborates on the execution of this step.

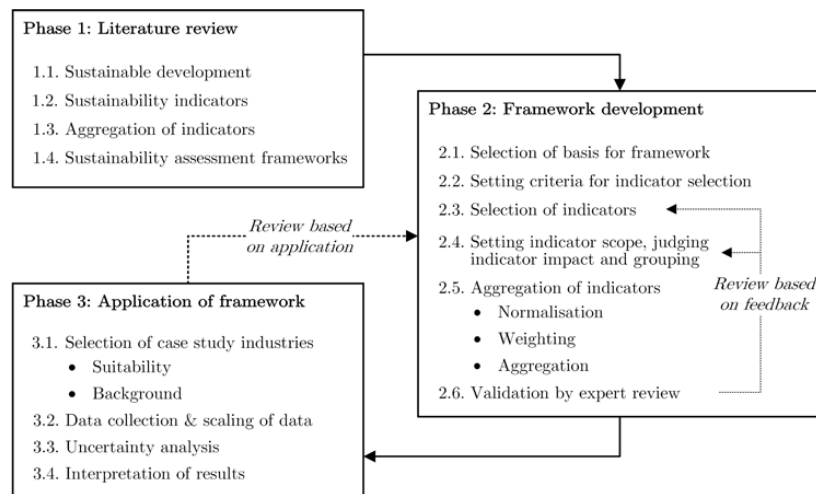


Figure 2. Overview of the methodology followed in the development of the framework.

Upon completion of Phase 2 (the development of the framework) the functionality and usability of the framework was further assessed by application to case study industries in Phase 3 of the methodology. Phase 3 began with the selection of suitable case study industries to be compared by using the framework (Section 4.3.1). Having selected the case study industries, collection and scaling of the required input data could commence. Sections 4.3.2 and 4.3.3 discuss the execution of these steps. An uncertainty analysis was then conducted to quantify the uncertainty associated with the results generated. This was done to ensure the appropriate interpretation of results given missing and incomplete information used to generate results. The details of the uncertainty analysis are discussed in Section 4.3.4. This is followed, in Section 5, by a presentation and interpretation of the results generated using the framework. The interpretation of the results aimed to allow the assessment of the functionality and usability of the framework and the potential utility of the results it generates.

Phase 2 of the methodology encompassed the steps in which the main structure, and therefore the inherent properties, of the framework was developed. The different methods that were considered in each step are outlined in Table A2 in Appendix A, along with the prominent literature sources in which the listed methods are discussed. The selection of a basis for the framework and setting the criteria for indicator selection (Steps 2.1 and 2.2) are unique to the requirements of any particular study and therefore, no methods or literature sources were indicated for these steps. Similarly, there are no specific methods for setting indicator scope, judging indicator impact and grouping indicators (Step 2.4) in literature, although some sources discuss these steps in general [31,33,35,52].

4. Proposed Assessment Framework

Following the methodology described in Section 3, a framework that uses publicly available sustainability information to compare the sustainability performance of different industries was developed. This section presents the decisions made in the development of the framework. The discussion starts with an outline of the structure of the developed framework (Section 4.1). This is followed by an elaboration on the decisions made in the construction of the framework (Section 4.2), with reference to the steps outlined Section 3. Each of these decisions has a potentially significant impact on the results generated by the framework and the rationale for the choice of each is therefore also discussed.

4.1. Framework Structure

Figure 3 illustrates the comparison of potential development opportunities as facilitated by the framework. Similar to most of the frameworks that make use of aggregated indicators discussed in Section 2 and listed in Table A1, notably Zhou et al. [33] and Krajnc and Glavic [31], the framework relies on sequential aggregation steps to move from sub-indicators to composite indices. Specifically, the framework is composed of sub-indicators (forming the bottom framework level), which are combined to form indicators (forming the intermediate framework level). These indicators are in turn aggregated to produce a single composite indicator, or index, for each dimension of the TBL (forming the top framework level). This allows the comparison of different potential industries at the hand of only three indices. To limit information loss and the subsequent increased inaccuracy, the three indices are not aggregated further to produce a single overarching composite indicator.

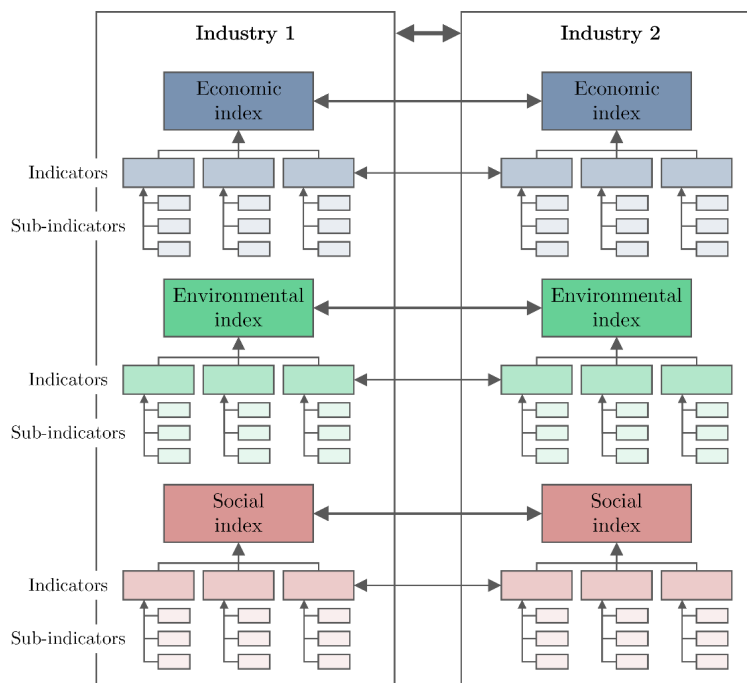


Figure 3. Framework structure facilitating comparison of potential development.

The framework was further designed to have a symmetrical indicator structure thereby ensuring no distortion of the weights of indicators in the different dimensions (Section 4.2.4 elaborates further in this regard).

Finally, the hierarchical structure of the framework allows the user to identify the individual underlying indicators or sub-indicators that contribute significantly to the relative superiority or inferiority of a specific development opportunity, ensuring transparency of results generated by use of the framework.

4.2. Framework Development

The decisions made during Phase 2 of the research methodology outlined in Figure 2 (Section 3) are discussed in depth in this section. Reference is made to the: (i) framework foundation; (ii) selection of indicators; (iii) scope and grouping of indicators, as well as the judgement of impact; (iv) weighting of indicators; (v) aggregation of indicators; and (vi) validation of the framework.

4.2.1. Foundation of the Framework

The framework depends on the use of quantitative data to compare different development opportunities in an objective manner. The increasing amount of sustainability information that is available in the public domain was seen as an opportunity and the rapid collection of this easily accessible data is therefore central to the utility of the framework. Using an existing reporting framework as basis for the present framework allows the user of the developed framework to find organizations active in the relevant industries elsewhere in the world and use the data which these organizations report according to the guidelines of the existing framework. This data can be used as basis for the comparison of the potential of developing these industries in a target country. As such, basing the present framework on an existing reporting framework or guideline has several advantages. Firstly, the required input data is available and easily accessible. Moreover, the data is already in the right form, eliminating or reducing the need to adjust the data. Secondly, the transparency and accuracy, and therefore credibility, of data are already proven to be acceptable.

Therefore, a decision was made that the framework will be based on one or more existing sustainability reporting frameworks or guidelines. In a previous work by the authors [10], five prominent international sustainability reporting frameworks were compared, using several criteria, to determine which of these frameworks would be most suitable to be used to compare the sustainability of different industries. It was found that the Global Reporting Initiative's (GRI) Sustainability Reporting Guidelines was the most suitable framework to be used in a comparison model, based on its almost universal global acceptance, the standardized nature of the indicators it uses and the comprehensive scope of its indicators. Based on this result, the GRI G4 Sustainability Reporting Guidelines were selected to serve as basis for the present framework.

4.2.2. Selection of Indicators

Using the GRI G4 Sustainability Reporting Guidelines as foundation for the present framework, indicators to be used in the framework had to be selected from those used in the GRI G4 guidelines. The selection of the underlying indicators was of particular importance as the strengths and the weaknesses of a composite indicator largely derive from the quality of the indicators it is composed of [35]. As the indicators used in the present framework are selected from the GRI G4 guidelines, which makes use of well-defined and tested indicators, the quality of the underlying indicators in the present framework are implied.

Niemeijer [53] states that the underlying indicators used to construct a composite indicator are generally selected according to either the data-driven approach (where data availability is the central selection criteria) or the theory-driven approach (where it is attempted to select the best possible combination of indicators to describe the system, also taking the availability of data into account). Zhou et al. [33] adds a third approach: the policy-driven approach, where indicators are selected specifically to comprehensively measure and assess the impact of a certain policy.

A theory-driven approach, with specific emphasis on using indicators for which data is available, was used in the present work. Making use of a theory-driven approach ensured all the dimensions of the triple bottom line were addressed, as is required in a comprehensive assessment of sustainable development potential. Further, taking the availability of data into account ensured that data collection would remain rapid and relatively simple, as the rapid comparison of opportunities is one of the objectives of the developed framework.

As a result of the nature of the developed framework, there were two specific requirements that had to be met by indicators to be of use in the present framework. Firstly, each indicator had to be generalizable for an entire industry, as the framework aims to compare entire industries. A single value, representative for the entire industry, should therefore be attainable for each indicator in the framework to allow comparison with the value of that indicator for another industry. Secondly, each indicator had to be applicable to an industry that is yet to be established. The framework specifically aims to facilitate the comparison of potential industries to facilitate better decision-making in terms

of which industries to develop in the economy. Indicators measuring changes in performance, for example, reductions in material or energy use were therefore not deemed applicable. Such indicators are useful when assessing sustainable development progress by using the GRI G4 Sustainability Reporting Guidelines, for example, but as industries that are not yet established are to be assessed with the framework developed in this study, only absolute measured were considered.

Further, in the development of the framework it was considered important that the framework is comprehensive and objective enough to produce dependable results, but remains easy to use and swiftly produces rapidly interpretable results. As such, limiting the number of indicators measuring each aspect was desirable and consequently this was treated as an additional consideration in the selection of indicators. Limiting the number of indicators measuring an aspect also prevents double-counting of the impact of that aspect, although double-counting can also be addressed by altering indicator weights, but would add to the time required for gathering information. Summary indicators that can integrate the results of other indicators were thus favored over indicators that provide a more detailed breakdown of information covered by other summary indicators. Including such summary indicators meant that detail indicators could be excluded without distorting the aggregate results and reducing the total number of indicators sampled.

The G4 guidelines make use of 91 indicators, consisting of 9 economic, 34 environmental and 48 social indicators. By application of the above-mentioned criteria to the G4 guidelines (i.e., removing all indicators that are either not generalizable for an entire industry or not applicable to an industry yet to be established) the number of indicators were reduced from 91 to 37.

A further five indicators were removed in accordance with the aforementioned objective of limiting the number of indicators addressing each aspect and preventing over-emphasizing the impact of some aspects in the framework. The indicators excluded under this criterion typically presented information already captured in other indicators in the G4 guidelines in a different manner so as to present a clearer picture of the actual sustainable development progress of an organization. Indicators presenting the energy intensity or greenhouse gas emissions intensity, for example, merely presents information already captured by other indicators (measuring energy consumption and the mass of greenhouse gas emissions in this case) in ratio form. Although this information aids the user by providing another perspective using the same information, it does not add new information or improve the accuracy of the results produced by the framework. These indicators were therefore deemed excessive in the framework developed here.

Thus, after all these exclusions, 32 of the original 91 indicators were left, consisting of 6 economic, 12 environmental and 14 social indicators. These were the preliminary indicators included in the framework. These preliminary indicators included in the framework were later adjusted based on the feedback received in the validation process (discussed in Section 4.2.6). To assess the coverage of the selection, the indicators were also assessed in terms of their linkage to the sustainable development goals (SDGs) as indicated in Table A4, Appendix C. A brief explanation of each of the final exclusions is provided in the Supplementary File S3.

4.2.3. Indicator Scope, Grouping and Judgement of Impact

The framework was aimed at the prospective assessment of development opportunities at industry-level and the GRI Sustainability Reporting Guidelines indicators used in the framework were originally developed for retrospective sustainability reporting at organization-level. As such, the scope statements of the indicators had to be revised. Although the essence of all the indicators remained the same, the exact inclusions were tailored to allow generalization of the indicators to represent information for a newly established industry, as opposed to representing retrospective information of only one organization. For example, the GRI G4 scope of indicator G4-EN8 (Water withdrawals by source) includes disclosure of the sources from which water is withdrawn, however, in the present framework the scope of this indicator was revised to exclude consideration of the sources from which water is withdrawn as these will vary for different organizations within an industry. As such, in the

present framework, indicator G4-EN8 measures only the mass of water withdrawn (irrespective of the source).

Further, as the framework makes use of quantitative comparison of development opportunities in terms of different indicators, indicators designed to present qualitative information in the GRI G4 guidelines had to be revised. Thus, in the framework, risk and impact scores were used to quantify indicators that measure predominantly qualitative aspects. These quantifications in terms of risk and impact scores were accomplished by making use of a risk quantification matrix. Risk matrices are commonly used in the quantification of risk in a variety of fields, most prominently in project management [54–56]. In this matrix, the vertical axis captures the perceived severity of the potential impact, while the horizontal axis captures the perceived likelihood or relevance of that impact actually occurring (where 1 is the minimum and 5 is the maximum for both axes). A combination of the perceived potential impact and the likelihood of that impact occurring determines the risk or impact score associated with a case.

Sub-indicators measuring similar aspects had to be grouped together in order to make the process of allocating weights more accurate. This helped prevent over-emphasizing some aspects that are measured by several indicators compared to aspects measured by fewer indicators. The GRI Reporting Guidelines already group indicators according to the aspect each one measures. After revision of the scope of all the indicators to be included in the framework, however, the grouping of some of the indicators were adjusted to ensure a logical framework structure. For example, Indicator G4-LA15 in the G4 guidelines (Supplier assessment for labor practices) was considered similar to indicators G4-HR3 through -HR6 and -HR11 (all referring to different human rights assessments). All these indicators were therefore grouped together to form indicator Soci-4 (Human rights assessments) in the framework.

Finally, the contribution measured by each indicator has to be judged in order to establish which indicators indicate positive impacts and which indicate negative impacts [33]. The nature of the impact has an influence on the subsequent normalization and aggregation steps (discussed further in Section 4.2.5). For example, the impact of generating higher financial earnings can be considered positive outcome, while the impact of producing higher greenhouse gas emissions can be considered to be a negative outcome.

4.2.4. Weighting of Indicators

The allocation of different weights to different indicators allows the effect of indicators that are deemed more important than others, perhaps due to industry-specific strategy or national policy, to be emphasized in a composite index. Weighting of indicators can be derived from statistical models or from participatory methods (see Table A2 in Appendix A) [35]. However, it is most common to use equal weighting (EW) of all indicators [29–31].

In the developed framework, the six indicators reflecting the industry performance in each dimension of the triple bottom line are all equally weighted as these indicators are all assumed to be of equal importance. The sub-indicators for every indicator are also equally weighted, but the weights of sub-indicators for different indicators do not necessarily have the same weight. As such, all indicators are of equal importance, but in the overall scheme all sub-indicators are not of equal importance. This is a result of the equal weighting of all the indicators—the relative weights of the sub-indicators depend on the number of sub-indicators of which an indicator is composed. For example, indicator Soci-4 is composed of six sub-indicators (therefore weighting $\frac{1}{6}$ each) while indicator Soci-5 is composed of only three sub-indicators (therefore weighting $\frac{1}{3}$ each). As all indicators are taken to be of equal importance, Soci-4 and Soci-5 both have a weight of $\frac{1}{6}$, but as a result each sub-indicator of Soci-4 has an implied overall weight of $\frac{1}{6} \times \frac{1}{6} = \frac{1}{36}$, while each sub-indicator for Soci-5 has an implied overall weight of $\frac{1}{6} \times \frac{1}{3} = \frac{1}{18}$. Equal weighting of all indicators, coupled with the symmetrical indicator structure (six indicators measuring each dimension of the triple bottom line), implies that all dimensions of the triple bottom line are assumed to be of equal importance. Further,

assigning equal weights to all indicators and not to all sub-indicators ensures that indicators composed from more sub-indicators are not implicitly more heavily weighted and therefore more important in the overall framework, as would be the case if all sub-indicators are equally weighted. This is typically desirable with sustainability indicators where all the dimensions are of equal importance to ensure progress toward balanced sustainability (as pointed out by, amongst others, Brandi et al. [30], Krajnc and Glavič [31] and Lozano [57]).

4.2.5. Aggregation of Indicators

Several different aggregation methods can be used. Linear aggregation, typically calculated as the weighted sum of the normalized indicators, is widely used due to its simplicity, transparency and accessibility. Geometric aggregation, calculated as the product of the normalized individual indicators each to the power of its weight, is also used in some cases. However, both these aggregation methods are compensatory in nature and therefore indicator weights express substitution rates (trade-offs) between indicators and not the relative importance. This compensatory logic, meaning that sufficiently good performance of some indicators can compensate for poor performance of others (referred to as compensability), is often an undesirable property [33,35,58].

To overcome the problems regarding compensability and the meaning of weights, a non-compensatory multi-criteria (NCMC) approach can be used. NCMC aggregation allows a compromise to be found between two or more equally legitimate and -important goals, without compensability. As such, indicator weights are interpreted as importance coefficients in non-compensatory methods [35].

Apart from addressing the problems regarding compensability and the meaning of indicator weights, NCMC aggregation also allows the use of both quantitative and qualitative information and does not require normalization of data, thereby limiting subjectivity in the aggregation process [58]. However, when using NCMC the magnitude of differences between indicator values for alternatives are not taken into account and, as such, the resulting composite indicator does not indicate the degree of superiority or inferiority of one alternative compared to another [35].

A non-compensatory multi-criteria (NCMC) aggregation logic was deemed most appropriate for the framework in this study. This choice is based on several considerations. As noted in the Handbook on Constructing Composite Indicators [35], multi-criteria problems, such as the comparison in the present framework, cannot be solved to find a single solution optimizing all the criteria at the same time (the so-called “utopia solution”). Instead an acceptable solution, allowing compromise, has to be found. However, compensability in the aggregation process might favor solutions that excel in only one or a limited number of dimension. NCMC aggregation is superior to the other methods in this respect as it does not reward outliers, since it only captures relative superiority or inferiority of industries with no regard to the extent of the advantage or disadvantage of an industry above another. This does, however, mean that without inspection of the value of individual underlying indicators, one cannot draw any conclusion as to the extent of superiority or inferiority of an industry compared to another. This also allows consistently good performance to potentially hide critically poor performance in a single or a few aspects. Cognizant of its shortcomings and the need to inspect the underlying indicators separately when drawing conclusions, NCMC aggregation, in which consistent performance is rewarded, was deemed most suitable for the purposes of the proposed framework.

Furthermore, the fact that information regarding the magnitude of indicator values is not captured in the aggregation process and no normalization is required allows the user to compare the composite indices for different dimensions. As only weights, which sum to a total of 1 for each dimension, are captured in the aggregation process, the performance of different dimensions can be compared directly. This is not the case when normalized indicator values are used, as these do not necessarily all sum to the same value for each dimension. The use of NCMC aggregation therefore allows and encourages sustainable development to be considered as an integrated system, instead of the traditional siloed consideration of the different dimensions of sustainable development.

4.2.6. Validation of the Framework

The aforementioned 32 preliminary indicators were used in the first iteration of the process in which the framework was first reviewed based on inputs from experts. The framework was then tested further by application to a case study.

To validate the framework, four experts were identified by discussion with the project leader and by recommendation from experts already contacted in the process of developing the framework. These experts represented several perspectives, including sustainability research, the private sector involved in metal beneficiation, as well as research on the economic beneficiation of metals in South Africa. Experts with this variety of expertise were purposely chosen to ensure a balanced and comprehensive review of the contents of the framework and its possible utility.

A short questionnaire was used to capture the feedback from the experts in a formal and structured manner. Prior to completion of the questionnaire, each of the experts were introduced to the background, structure and objectives of the project. The questions posed in the questionnaire were structured to provide guidance in the response of participants but remain considerably open-ended as to not restrict the response of participants and to provoke an elaborate explanation of any perceived shortcomings. Among others, the questionnaire requested feedback on whether the framework was comprehensive enough and whether the experts considered the framework as potentially useful. Experts were also encouraged to voice any concerns or potential shortcomings that they noticed.

The consultation process with the experts produced several insights that were used to improve the indicators included in the framework. A summary of the final indicators included in the framework (after incorporation of the insights from the experts) is presented in Table A3 in Appendix B.

4.3. Case Study Methodology

Applying the developed framework to case study industries formed the third phase of the methodology used in this project (as illustrated in Figure 2) and served to test the utility of the framework and identify the shortcomings of its use. This phase therefore formed an important part of the process of validating the framework and the results it generates. It also enables the analysis of the strengths and weaknesses related to the use of sustainability indicators in the analysis of industries.

4.3.1. Case Selection

The first step in the application of the framework to a case study was the selection of appropriate industries to be compared in the case study. Many industries could be used to illustrate and test the utility and shortcomings of the framework. However, it was important to use industries for which the relevant information, of sufficient quality, was readily available (generally implying that globally well-established industries were favorable). It was further regarded to be of value if the case study industries were not only relevant in terms of validation of the framework, but also in terms of development in a country.

Given the increasing drive of several (mineral rich) developing countries to develop industries that increase the local beneficiation of mineral resources, mineral beneficiation industries were an ideal case study [59,60]. Platinum beneficiation was specifically chosen as platinum is used in a wide range of well-established industries globally, with accurate information generally easily attainable for many of these industries. Having selected platinum as a case study, South Africa was chosen as the focal region, as platinum is of specific economic importance to the country. South Africa is responsible for about 70% of annual global platinum production [61]. However, 89.5% of the platinum produced in 2013 was exported in the form of non-beneficiated metal [62]. The South African government has undertaken to promote the local beneficiation of its mineral resources, including platinum, in order to capture more value from these resources [63]. As such, the beneficiation of platinum in South Africa was an ideal and relevant case on which to test the utility of the framework, with the results of potential use to policymakers.

The catalytic converter industry is especially well suited as it is the largest platinum consuming industry globally [61] and a catalytic converter manufacturing industry is already established in South Africa. A large number of companies are therefore active in the international and national catalytic converter industries and subsequently a large amount of relevant and suitable information is available for these industries. The importance of the automotive industry in South Africa, including the catalytic converter industry, is also recognized at policy level [63]. The catalytic converter industry was therefore selected as the first case study industry.

The platinum jewellery industry is the second largest consumer of platinum globally [61] and therefore has advantages similar to those of the catalytic converter industry in terms of availability of information. Further, development and integration of platinum jewellery fabrication capabilities with the fabrication of gold and diamond jewellery in South Africa is also being encouraged at policy level [63]. The platinum jewellery industry was therefore selected to be the second case study industry.

Finally, with the significant global emphasis on fuel cells as part of the global energy mix of the future and the potential for establishing a fuel cell industry in South Africa, the fuel cell industry would have been a relevant industry to use to test the utility of the framework. However, the authors could find no suitable company that produces fuel cells and makes use of the GRI Sustainability Reporting Guidelines. The appropriate information could therefore not be gathered and the fuel cell industry could therefore not be used as part of the case study. This problem highlights an important drawback of making use of publicly available sustainability information in the framework as emerging industries are unlikely to have suitable information available for analysis. Thus, only the catalytic converter and platinum jewellery industries were analyzed in the case study. Detailed maps of the production and use, respectively, of platinum metal more broadly were also developed and are contained in the Supplementary Files Figures S1 and S2.

4.3.2. Data Collection

Large, pace-setting organizations were chosen to represent the case study industries in this study as these companies likely provide a close to best-case comparison, making the results of the comparison more conclusive. If an industry is superior to another in some dimension, based on the best-case scenario for both industries, little doubt can exist that the industry is indeed superior to the other (in general).

The organization chosen to represent the catalytic converter industry was selected because it is one of the largest global producers of catalytic converters, accounting for approximately a third of all catalytic converters used in light vehicles globally at the time of the study. This organization is globally acclaimed and has been producing catalytic converters for more than forty years. The organization further also has operations in more than 30 countries worldwide, which was considered an advantage as country- or region-specific effects in the data will be more balanced and therefore less pronounced, making the data more generic and likely more accurate, irrespective of the target country. Similar to this organization, the organization chosen to represent the platinum jewellery industry is also considered one of the global leaders in its industry, with operations in 25 countries, which was once again seen as an advantage. At the time of the study, it was estimated that this organization accounted for more than three percent of global platinum consumption for jewellery purposes.

Having chosen the organizations that were used to represent the catalytic converter industry and the platinum jewellery industry, the authors proceeded to collect the required data from the organizations' annual financial and sustainability reports. 2014 was used as subject year for all data and calculations as this was the latest year for which sufficient data could be attained when the case studies were performed.

The data collection process was complicated in several ways. The first obstacle was that different organizations used different methodologies to calculate some of the indicator values, although this was not a great concern for the most part as the GRI indicators are generally well-defined. A much more pronounced problem was the fact that most organizations do not report all the indicators that

form part of the GRI reporting guidelines as all disclosures are voluntary. Organizations may exclude specific indicators for various reasons. For example, companies may only report indicators that are deemed material to their specific operations, exclude indicators that are not measured adequately for their operations or exclude indicators that disclose information that may be considered sensitive or proprietary. As a result, data could not be found for indicators Envi-1.1, -1.2, -3.2, -4.1, -4.2, -5 and Soci-3 for one or either of the compared industries.

The analysis and imputation of missing data is an extensive and rapidly developing research field, with several implicit (replacing missing values by those from related data sets) or explicit (statistical modelling) imputation techniques that can be used to estimate missing indicator values [64,65]. However, the imputation of data will always affect the accuracy and the credibility of the composite indicator(s) in which that data is used [35]. For the present work, imputation of missing indicator values was not considered as no data could be found for the missing indicators, although extensive effort was made to find such data in industry reports and annual reports by similar organizations. This meant that neither explicit nor implicit modelling could be used to estimate missing values.

Fortunately, the majority of the indicators excluded from the framework due to lack of data were sub-indicators used in conjunction with others to describe a specific aspect. The exclusion of these sub-indicators did therefore not result in the complete neglect of that aspect, although that aspect was less fully described. Indicators Envi-5 and Soci-3 were, however, both stand-alone indicators used to measure the percentage of products and packaging materials reclaimed and the average hours of training employees receive, respectively. Exclusion of these indicators thus meant that these aspects were no longer considered in the framework. The indicators for which data could not be found were still included in the uncertainty analysis to account for the effect of the missing data (as described in Section 4.3.4).

The increased adoption of policies and regulations such as Directive 2014/95/EU of the European Parliament [66], which requires certain large organizations to include non-financial disclosures in their annual reports, is expected to result in an increase in availability of consistent and comparable sustainability information. Further, the concept of integrated reporting is drawing increased attention globally and it is becoming increasingly plausible that integrated reporting may become mandatory to many organizations in the foreseeable future. This would further increase the availability of sustainability information in the public domain and would foreseeably reduce instances in which indicators have to be excluded from the framework due to a lack of data for those indicators. Improvements in integrated reporting may also lead to the establishment of generally accepted auditing processes for disclosures that resemble those currently limited to financial auditing. This will support improved data reliability. The fact that these developments are still unfolding, clearly restricts the current applications of the proposed framework to only being used as an early stage pre-feasibility assessment aid. Furthermore, these developments may render the GRI G4 guidelines obsolete in future, meaning the framework proposed in this work would have to be substantially revised.

4.3.3. Scaling of Data

The data collected for each organization had to be scaled in two ways. Firstly, neither of the organizations used to represent the case study industries in this study were active in only the subject industries. Their operations spanned several industries and as a result the total values reported for all their operations had to be adjusted to only represent the relevant portion of their operations where relevant. Secondly, this data had to be scaled from organization- to industry-level, such that the data represent an entire industry and not only a single organization in that industry.

For both industries, the first scaling was based on the percentage of total sales contributed by the relevant portion of the organization's operations. For the organization representing the jewellery industry, for example, it was calculated that 46% of the total sales reported by the organization was from the sale of platinum jewellery pieces. All subsequent indicator values that were dependent on organization size, for example greenhouse gas emissions or number of employees, were therefore

scaled by this 46%. This scaling is, of course, based on the very crude assumption that the scaled indicator values are directly and linearly related to sales revenue. At the lack of any better, easily attainable, scaling parameters, this assumption was nonetheless used, but the percentage value was varied uniformly by 10% in either direction (i.e., 36% to 56%) during the sensitivity analysis in an attempt to account for the uncertainty in this assumption.

The second scaling of the data—from organization- to industry-level—was performed using two different methods. As the annual sales revenue generated by the global platinum jewellery industry is not freely available and there is little consensus over the exact amounts in the few industry reports that report sales figures, the mass of platinum used annually was used in this scaling. The mass of platinum consumed by the organization representing the case study industry amounted to about 3.3% of global platinum use for jewellery purposes in 2014. Assuming a platinum jewellery industry consuming 5% of global platinum demand for jewellery purposes can be established in South Africa, all indicator values were scaled by 1.52 (5/3.3) to represent an industry. The assumption that a platinum jewellery industry consuming 5% of global platinum demand for jewellery purposes can be established in South Africa is arbitrary and was varied uniformly between 3 and 7% in the uncertainty analysis. It will later be shown that this arbitrary assumption of 5% has little influence on the conclusions that can be drawn from the comparison.

The scaling for the catalytic converter industry was simpler as the catalytic converter industry is already established in South Africa and thus data of the revenue generated by export of catalytic converters is readily available. For the scaling in this case, the value of total exports of catalytic converters from South Africa for 2014 as reported by the South African Automotive Industry Export Council [67] was used in conjunction with the total revenue generated from sales of catalytic converters calculated for the organization. The catalytic converter exports from South Africa amounted to 31.2% of the value of sales of catalytic converters by the organization. To represent an industry, all relevant indicators values for the organization were therefore scaled to 31.2% of their original values. The assumption was thus made that the catalytic converter industry remains as it is. Thus, the South African industry accounts for approximately 13 % of global production [62]. The case scenario thus compares the TBL impact of an industry already present with the potential TBL impact of a new industry based on experiences in other geographies. This illustrates the framework's ability to include the comparison of both existing (in the focal location) and potential (yet at least existing in other jurisdictions) industries.

4.3.4. Uncertainty Analysis

Various factors can influence the certainty associated with the outputs generated by application of the framework. Embedded uncertainty in the input data, as well as the uncertainty related to assumptions and estimates made in the calculation and scaling of the input data are some of the most prominent factors that introduce uncertainty. Uncertainty analysis was conducted to account for these uncertainties and thereby allow the user to take these into account when drawing conclusions from the framework outputs.

Monte Carlo simulation, using the @Risk[®] extension for Microsoft Excel[®], was used to conduct the uncertainty analysis. Ten thousand iterations of random input values were used. Uniform distribution functions were used for indicator values that were very uncertain, while triangular distributions were used for indicator values for which clear minimum and maximum values existed. All risk and impact scores were varied one point up and one point down from the allocated score in a uniform distribution in which only discrete values were allowed (for example, a score of 5 was varied uniformly between the discrete values 4, 5 and 6).

The indicators for which no data could be found were also included in the uncertainty analysis. As any of the two industries could be superior in terms of these indicators, the values were varied from the jewellery industry being superior to equal performance by both industries to the catalytic converter industry being superior. As such, all possible outcomes were accounted for and given equal likelihood.

5. Case Study Results

This section presents the results generated by comparing the platinum jewellery industry and the catalytic converter industry using the framework. Figure 4 illustrates the outcome of the comparison. The catalytic converter industry was found superior in terms of the economic and social dimensions, while it was found inferior in terms of the environmental dimension. The confidence associated with the ranking of each dimension, based on the results of the uncertainty analysis, is also indicated in Figure 5. The case study values used for all the indicators in the comparison of the industries are presented in Table A3 in Appendix B.

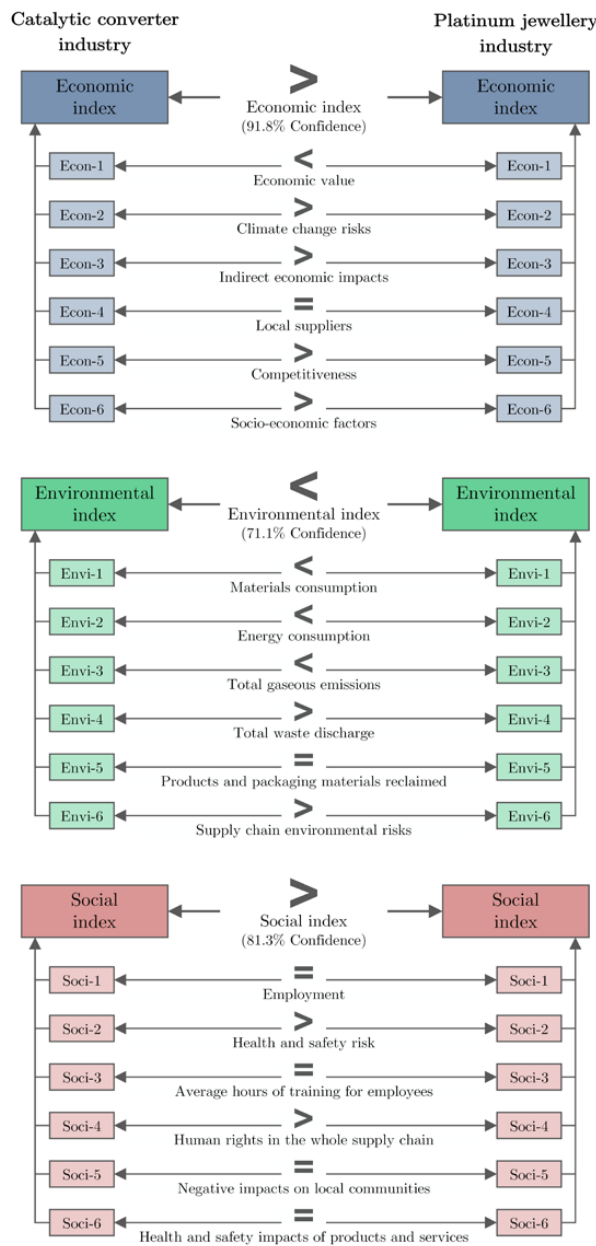


Figure 4. Results generated by using the framework to compare the platinum jewellery industry and the catalytic converter industry.

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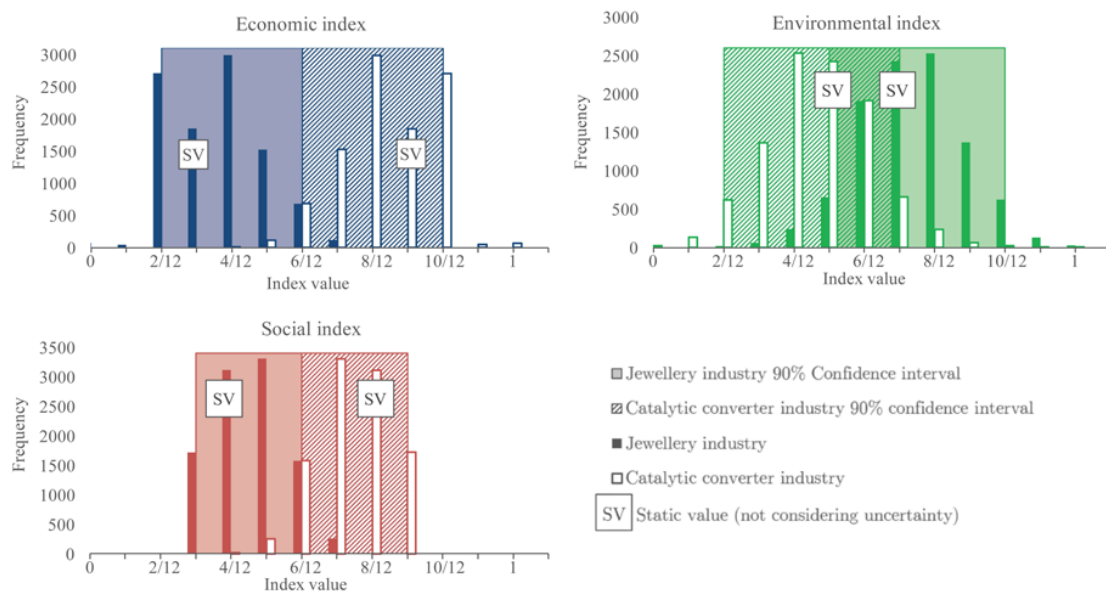


Figure 5. Index values and 90% confidence intervals for comparison of the platinum jewellery industry and the catalytic converter industry by using the framework.

Considering the economic index, the jewellery industry was superior in terms of indicator Econ-1 (Economic value) and the industries were rated equally in terms of indicator Econ-4 (Use of local suppliers). In the environmental dimension the jewellery industry was superior in terms of indicators Envi-1 (Material consumption), Envi-2 (Energy consumption) and Envi-3 (Total gaseous emissions) and the industries were rated equally in terms of indicator Envi-4 (Total waste discharge). Finally, in the social dimension the catalytic converter industry was superior in terms of indicators Soci-2 (Health and safety risk) and Soci-4 (Human rights in the supply chain), with the industries rated equally in terms of indicators Soci-1 (Employment), Soci-3 (Average hours of training for employees), Soci-5 (Negative impacts on local communities) and Soci-6 (Health and safety impacts of products and services).

Figure 5 presents the scores attained by each industry when the uncertainty in the input variables are considered, in terms of the three dimensions of sustainability. The 90% confidence intervals and the static values, when uncertainty is not taken into account, are also indicated. The scores were attained by adding the weight of each indicator in which a specific industry is superior to its score for that dimension (a total score of one could therefore be attained per dimension). The jewellery industry, for example, attained a total score of three twelfths ($1/6 + 1/12$) in the economic dimension as it was superior in terms of indicator Econ-1 and the industries were rated equally in terms of indicator Econ-4. The catalytic converter industry therefore attained a score of nine twelfths in the economic dimension.

5.1. Economic Index

The uncertainty analysis results indicate that the mode and median values for the economic index of the jewellery industry are both four twelfths (0.333), while the mean value is 0.297. As only two industries were considered in the analysis, the results of the uncertainty analysis for the catalytic converter industry is the symmetrical opposite of that for the jewellery industry: the mode and median values are both eight twelfths (0.667) and the mean value is 0.703. The mode and median values differ from the static values, indicating that the uncertainty in input values causes a slight shift in index value from the static value towards the central value of six twelfths (where the economic potential of the jewellery industry is considered equal to that of the catalytic converter industry). However, the 90% confidence intervals of the industries (Figure 5) only meet at the six twelfths-point and never overlap,

which means the likelihood of the jewellery industry surpassing the catalytic converter industry in terms of economic index is very small. As indicated in Figure 5, the catalytic converter industry can be considered superior with 92% confidence.

The superiority of the catalytic converter industry in the economic dimension in the present investigation stems from its strong performance in terms of indicators Econ-2, Econ-3, Econ-5 and Econ-6. These are all indicators that are measured in terms of risk or impact scores which implies that the scaling of the data from organization- to industry-level has little impact on the results for this dimension, as risk and impact scores are considered scale independent. The arbitrary assumption that a jewellery industry consuming 5% of the total platinum consumption for jewellery purposes in 2014 can be established in South Africa is therefore not of significance in the final ranking of the industries in terms of the economic index.

5.2. Environmental Index

The static values for the environmental index show that the jewellery industry is considered slightly superior, scoring seven twelfths to the five twelfths of the catalytic converter industry. However, when the uncertainty in the input values is considered, it becomes clear that there is little to choose between the industries in the environmental dimension. The mode and median index values for the jewellery industry are eight twelfths and seven twelfths, respectively, resulting in a mean value of 0.612. The index values of the industries are concentrated close to the center value of six twelfths where the industries are considered to have equal potential. It is therefore not surprising that the 90% confidence intervals of the industries overlap in the region between five and seven twelfths and that the confidence of the jewellery industry being superior in this dimension is only 71%.

The slight superiority of the jewellery industry in this dimension is a result of strong performance in indicators Envi-1 (Material consumption), Envi-2 (Energy consumption) and Envi-3 (Total gaseous emissions). These indicators are scale-dependent and the scaling of the organization-level data to industry-level therefore has a significant impact on the performance of the jewellery industry relative to the catalytic converter industry in this dimension.

5.3. Social Index

The catalytic converter industry is superior in the social dimension with a static score of eight twelfths, compared to the four twelfths of the jewellery industry. The uncertainty analysis results show that both the mode and median values for the jewellery industry are five twelfths, and the mean value is 0.380. Similar to the economic dimension, the 90% confidence intervals only touch at the halfway point, indicating that the likelihood of the catalytic converter performing better than the jewellery industry in the social dimension is high (more than 81%, with about a 15% chance of the industries being equal).

The industry scores are once again very close, with the catalytic converter industry gaining its slight advantage with strong performance in indicators Soci-2 (Health and safety risk) and Soci-4 (Human rights in the supply chain). The industries are tied even at the other four indicators (with the exception of Soci-3, Average hours of training for employees, for which data could not be found). Similar to the economic index, scaling had a minor influence on the results for the social dimension. No data could be found for indicator Soci-3 and thus only indicators Soci-1.1 and Soci-2 were scale-dependent. The arbitrary assumption that a jewellery industry consuming 5% of the total platinum consumption for jewellery purposes in 2014 can be established in South Africa therefore has little influence on the ranking of the industries in the social dimension.

5.4. Brief Perspective on the Results

The relative overall superiority of the catalytic converter industry compared to the jewellery industry supports the current development policy priorities in South Africa which focusses more strongly on the automotive industry than the jewellery industry (prominently through the Automotive

Production and Development Programme or APDP). The development of a platinum jewellery industry in South Africa is not a policy priority at the moment, although the potential of developing it along with the gold and diamond jewellery industries is recognized in the Beneficiation Strategy published in 2011 [63]. Further, although the results of the comparison indicate that the catalytic converter industry is superior to the jewellery industry based on data from 2014, the long-term sustainability of the catalytic converter industry is debatable. Catalytic converters can be seen as an interim solution that will only be useful until a better solution to the emission problem is found. However, internal combustion engines could remain important in the automotive industry in the medium term. On the other hand, the long-term sustainability of the platinum jewellery industry can also not be guaranteed due to its dependence on cultural trends and societal preferences. However, the relative rarity, useful properties and appearance of platinum means the likelihood of it becoming obsolete in the global jewellery market is likely slim. These developments highlight the need to not use the type of framework developed in this paper in isolation, but as another source of information in the decision-making process. The goal of the developed framework is to facilitate the efficient compilation of sustainability information as available in the public domain to provide a further dimension for decision-makers to consider and improve their overall decision-making process in relation to deciding on specific industries to support.

6. Discussion

Given the results from the case study, this section presents a S.W.O.T. analysis of the framework, based on observations that were made in the development of the framework and the application of the framework to the case study. Based on these observations, several recommendations are made for improvement of the framework, both in terms of theoretical rigor and practical usability. Observations are also made regarding the use of publicly available sustainability information to inform industrial policy in general.

6.1. S.W.O.T. Analysis of the Framework

Figure 6 presents a summary, in the form of a basic strengths, weaknesses, opportunities and threats (S.W.O.T.) analysis, of the utility and shortcomings of the framework as became apparent in the application of the framework and the subsequent interpretation of the results. The characteristics of the framework listed in Figure 6 are all inherent to the framework and its use and can therefore not be addressed easily. Recommendations for improvements are therefore discussed separately in Section 6.2.

Figure 6 lists several strengths of the framework. It is noted that the framework achieved the objective of facilitating the rapid comparison of different potential industries. The results generated by the framework can also be interpreted by inspection of the underlying indicators and sub-indicators that quantify each dimension. By such inspection, specific problem areas can be identified for subject industries, allowing effective consideration of these aspects in the decision-making process. Holistically strong performance by an industry is also rewarded, thereby ensuring that sustainability is considered as a whole and that industries that only perform well in some of the dimensions of sustainable development are penalized accordingly. Further, the uncertainty analysis, which is considered to be a crucial part of the working of the framework, contributes significantly to the credibility of the results and the accuracy of the interpretation of the results. Finally, a very notable strength of the framework is its generic nature that stems from the generic nature of the GRI G4 sustainability reporting guidelines on which it is based. This makes the framework applicable to all mineral beneficiation industries and industries outside this realm.

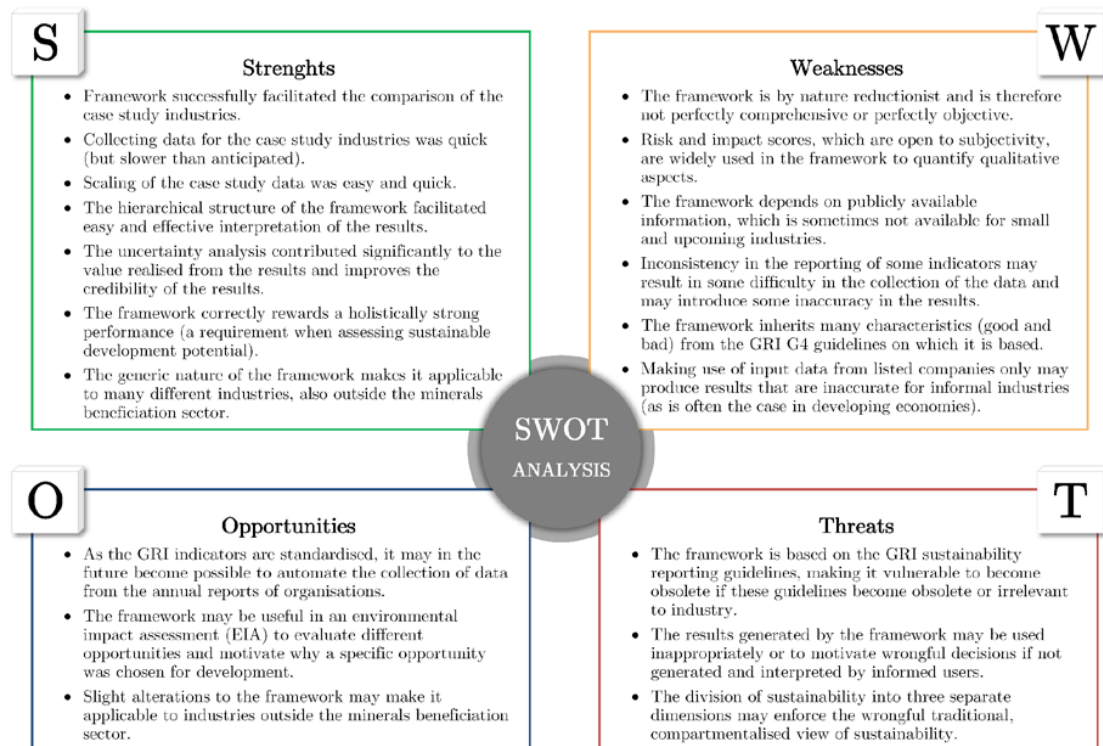


Figure 6. A summary of the utility and shortcomings of the framework in terms of a S.W.O.T. analysis.

Several weaknesses of the framework can also be identified. It can firstly be noted that the framework is by nature reductionist—a reduction or simplification of a complex reality—and therefore not perfectly comprehensive or -objective. The use of risk and impact scores are, for example, a subjective quantification of qualitative aspects. Further, the framework inherits many characteristics (good and bad) from the GRI G4 sustainability reporting guidelines on which it is based. The information reported according to the GRI G4 guidelines, which the framework uses as input data, for example, is typically reported by large, listed-companies, operating in developed (first-world) economies. Therefore, the results generated by using such input data may not necessarily be accurate for industries in developing (third-world) economies that may consist of small and/or informal enterprises. Further, peculiarities specific to some industries may be overlooked due to the generic nature of the framework and the indicators on which it is based. This underlines the fact that the framework can only be used for the very initial, scoping-phase filtering of development opportunities and that the thorough scrutiny of the results generated is of crucial importance. Further, the use of publicly available information is central to the working of the framework and therefore the framework cannot be used for industries if the correct data is not available (small, upcoming or informal industries, for example). Finally, inconsistency in the reporting of some indicators may result in some difficulty in the collection of the data and may introduce some inaccuracy in the results.

Figure 6 also identifies some opportunities and threats with regard to the framework. Firstly, the use of standardized, GRI indicators presents an opportunity in that it may become possible to automate the collection of data from the annual reports of organizations. However, this characteristic also presents a threat: the framework will become obsolete if the GRI sustainability reporting guidelines become obsolete or irrelevant to industry. Further, the generic nature of the framework may make it applicable industries beyond the initial scope of industries for which it was developed. The framework may even be useful in an application as far removed from its initial purpose as serving to evaluate different opportunities and motivate why a specific opportunity was chosen for development in an

environmental impact assessment (EIA). However, a risk also exists that the results generated by the framework may be used inappropriately or to motivate wrongful decisions if not generated and interpreted by informed users. Finally, the division of sustainability into three separate dimensions may enforce the wrongful traditional, compartmentalized view of sustainability.

6.2. Recommendations for Improving the Framework

Several recommendations that can be made for improvement of the framework can be identified. As the framework makes use of retrospective data to compare industries, the long-term future prospects of the subject industries are neglected. The framework does not, in its current form, take the expected trends in sector development and growth into account explicitly (this is left to be considered by decision-makers alongside the results generated by the framework). It might be sensible to incorporate this into the framework, such that industries with clear future upside in terms of development potential is favored in the results generated (the future growth of the catalytic converter industry, for example, may be expected to be considerably lower than that of the fuel cell industry). When incorporating this into the framework, it might be sensible to also consider the structure of the value chains of the subject industries explicitly, to aid in the quantification of the development potential of an industry. Some value chain structures may be more appropriate and favorable for development in some economies, based on existing industry structures or country-specific policy priorities.

Further, in the application of the framework to the case study industries, it has been noted that some improvements might be made in terms of the use of input data. Firstly, industry average values can be used for input values to the framework instead of using only data from a single organization. This will ensure that the input data is representative of the industry. It might also be worth investigating a method of quantifying the appropriateness of the input data before it is used to generate results. This might entail, inter alia, setting clear criteria for the selection of organizations from which data is gathered and mapping out of distortions and embedded effects in the data as a result of region-, country- or organization-specific events, or outlier events. Furthermore, it might be sensible to include the size of an industry in the allocation of risk or impact scores. This would ensure that potentially larger industries are penalized more for impacts than smaller industries, as impacts of the same severity for a smaller industry will likely be less detrimental overall.

Finally, it is recommended that the indirect economic impacts of an industry are emphasized more in the framework. Indicator Econ-3 quantifies indirect economic impacts in the framework and considers a vast array of impacts. This indicator quantifies, amongst others, the impact of the vertical, horizontal and lateral economic linkages generated by an industry, the impact of using the products and services of the industry, the impact of the industry on public infrastructure, the impact of the industry on the skills and knowledge amongst a community or in a geographical region. These impacts may all in their own right have far reaching consequences and it seems insufficient to collectively quantify these impacts in terms of only one indicator. It is therefore suggested that the weighting of this indicator be adjusted to make up a larger portion of the economic dimension (taking care to ensure all the dimensions remain equally weighted). It is further also suggested that the indicator be divided into several sub-indicators to facilitate better quantification of all the aspects it includes.

Indicators Econ-5 and Econ-6 quantify the potential competitiveness and socio-political fit of an industry. Local factors that may influence the competitiveness of an industry are considered, as well as the potential effects that political and regulatory factors may have on the success of the industry. Although considered implicitly, the fit of an industry in terms of the national and regional development goals of the target country are not taken into account explicitly. Developing an indicator that specifically quantifies this strategic fit of the industry in the target country may further improve the utility of the framework.

6.3. Discussion of the Use of Publicly Available Sustainability Information for Selecting Industries for Development

Notwithstanding the challenges identified throughout the article, it seems clear that there could be substantial potential in using publicly available sustainability information to provide a first insight into the sustainability performance of different existing industries to inform development policy. However, the current challenges regarding data quality, data availability, level of disclosure (company, not product) and scope of disclosure (not according to country borders) still hinder the process from being easily automated and the granularity of the results from being ideal for informing policy. As the ubiquity and quality of public disclosures improve, some of these challenges will likely be resolved.

7. Concluding Remarks

The framework proposed (and publicly available sustainability information in general) has potential to be useful as a tool that aids in the analysis of developmental impact of industries. It is, however, also clear that much work is still required in terms of further expanding the proposed framework to include the aforementioned suggestions and identifying complimentary tools that can be used to make the results it generates more accurate and useful. The process of further developing and expanding the framework in its current form, will necessarily remain complex as many of the strengths that warrant the existence of the framework, such as its ease-of-use, are derived from its use of the GRI reporting guidelines as basis, but using these guidelines also introduces some inherent weaknesses. Improving the framework will therefore remain delicate in terms of finding a balance between, on the one hand, maintaining the ease-of-use of the framework and, on the other hand, ensuring the results it generates are sufficiently comprehensive and accurate, and therefore useful in decision-making. This article has introduced a novel structured approach to attaining sustainability information for IPA decision-making. It is hoped that it will also encourage new and different approaches in this field in the future that can capitalize on the expected improvements in the field of public corporate disclosures.

Supplementary Materials: To perform the analyses described in this paper, it was necessary to gain a detailed understanding of platinum production processes and uses. To support the attainment of this understanding, detailed maps of (i) platinum production processes; and (ii) platinum uses were constructed by gathering information from various sources [68–77]. These maps are included as supplementary materials for reference by others aiming to do research focused on the platinum industry. The map of the platinum production processes is presented in Figure S1: Platinum production processes; and the map of the platinum uses in Figure S2: Platinum uses. Furthermore, towards more complete disclosure and to support reproducibility, a third supplementary file (S3) provides concise reasons for every GRI G4 indicator excluded from the proposed framework. These supplementary files are available online at www.mdpi.com/2071-1050/10/3/878/s1.

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Appendix A

Table A1. Relevant research work on sustainability assessment.

Study	Level of Assessment	Target Industry	TBL Dimensions Addressed	Aggregation of Indicators	Objective
Labuschagne et al. [78]	Project-level	Process industry	All	None	Assess sustainability of business operations.
Chee Tahir and Darton [79]	Organization-level	None	Organization-specific dimensions with high impact.	None	Present a method for assessing the sustainability of a business operation.
Krajnc and Glavic [80]	Organization-level	None	All (predominantly environmental).	None	Propose a list of indicators to assess the sustainability level of a company.
Singh et al. [52]	Organization-level	Steel industry	All	5-point rating system and Z score method [81]	Present a method for development of a composite sustainability performance index that measures the sustainability performance of an organisation.
Long et al. [82]	Organization-level	Iron & steel industry	All	Linear aggregation (using AHP to establish indicator weights).	Propose a sustainable assessment system specifically designed for Chinese iron and steel firms.
Salvado et al. [83]	Organization-level Supply chain-level	Automotive industry	All	Linear aggregation (using AHP to establish indicator weights).	Propose a sustainability index that provides companies with information about their TBL sustainability, at both individual and supply chain level.
Ghadimi et al. [84]	Product-level	Automotive components manufacturing industry	All	Linear aggregation of fuzzy input data (using fuzzy AHP to establish indicator weights).	Propose a weighted fuzzy assessment method for product sustainability assessment.
Study	Level of assessment	Target industry	TBL dimensions addressed	Aggregation of indicators	Objective
Winroth et al. [85]	Factory-level	None	All	None	Identify a list of performance indicators relevant for a production manager.
Garbie [86]	Organisation-level	Manufacturing industry	All	Linear aggregation (using AHP to establish indicator weights).	Modelling the required components and the introduction of a new assessment framework for assessing sustainability.
Vinodh et al. [87]	Organisation-level	Manufacturing industry	All	Linear aggregation	Propose a fuzzy-logic-based sustainability evaluation decision support system for manufacturing organizations.
Lodhia and Martin [88]	Organisation-level	Mining industry	All (using integrated indicators)	None	Propose corporate sustainability indicators for a major Australian diversified resources company and engaged with expert stakeholders in determining the indicators' value and explanatory capacity.
Chen et al. [36]	Factory-level	Manufacturing industry	N/A	N/A	Present a review and evaluation study of existing assessment tools for factory sustainability assessment to clarify the difference between these tools.

Table A2. Summary of the steps in Phase 2 of the development of the framework (with notable literature sources for each step).

Step	Description	Methods Used in Literature	Literature Sources
Selection of basis for framework	Selection of an existing reporting framework to serve as basis from which selected indicators can be used in the present framework	Specific to every project.	
Setting criteria for indicator selection	Setting appropriate criteria that have to be met by all indicators to be included in the framework.	Specific to every project.	
Selection of indicators	Selection of aspects to be quantified. Selection of appropriate indicator(s) to measure each aspect.	Data-driven approach Theory-driven approach Policy-driven approach	Zhou et al. [33] OECD and European Commission [35] Niemeijer [53]
Setting indicator scope, judging indicator impact and grouping	Setting scope of what aspects are included in each indicator. Establish whether each indicators measure a positive or negative impact. Structure indicators according to sub-groups of phenomenon (if applicable).	Specific to every project.	Zhou et al. [33] OECD and European Commission [35]
Aggregation of indicators Weighting of indicators	Assign weights to indicators to account for the relative importance of the aspects measured.	Equal weighting Statistical methods (using statistical analysis of large datasets, including principal components analysis, factor analysis, data envelopment analysis, the benefit of the doubt approach and unobserved components models). Participatory methods (making use of expert knowledge by consultation of industry experts, including the budget allocation process, analytic hierarchy process and conjoint analysis).	Brandt et al. [30] OECD and European Commission [35]
Normalization of indicators	Normalize indicators to allow aggregation of indicators measured in different units.	Ranking Min-max Distance to a reference Percentage of annual differences	Krajnc and Glavič [31] OECD and European Commission [35] Sikdar et al. [32] Zhou et al. [33]
Aggregation of indicators	Aggregate indicators into one index or a few indices.	Linear aggregation Geometric aggregation Non-compensatory multi-criteria (NCMC) aggregation	Munda and Nardo [58] OECD and European Commission [35] Zhou et al. [33]
Validation by expert review	Collection of feedback from knowledgeable people on the selected indicators and the structure of the framework.	Delphi Method Interview and/or questionnaire	Geist [89] Flick [90]

Appendix B

Table A3. Indicators and sub-indicators used in the framework, including weights and case study values.

ID	Name	Units	Weight	Impact	Jewellery Industry	Cat. Conv. Industry	Jewellery Industry Score	Cat. Conv. Industry Score
Economic indicators								
Econ-1	Economic value	Expected earnings	1/6	1	US\$ 339 944 523	US\$ 94 954 290	3/12	9/12
Econ-2	Climate change risks	Risk score	1/6	1	0	3	0	0
Econ-3	Indirect economic impacts	Impact score	1/6	1	2	4	0	0
Econ-4	Local suppliers	Percentage of operating cost	1/6	1	85%	85%	1/12	1/12
Econ-5	Competitiveness	Impact score	1/6				0	1/6
Econ-5.1	Factor conditions	Impact score	1/4	1	5	5	1/8	1/8
Econ-5.2	Demand conditions	Impact score	1/4	1	2	5	0	1/4
Econ-5.3	Related & supporting industries	Impact score	1/4	1	7	7	1/8	1/8
Econ-5.4	Rivalry	Impact score	1/4	1	-6	-3	0	1/4
Econ-6	Socio-economic factors	Impact score	1/6				0	1/6
Econ-6.1	Political factors	Impact score	1/3	1	5	7	0	1/3
Econ-6.2	Regulatory factors	Impact score	1/3	1	1	1	1/6	1/6
Econ-6.3	Cultural & demographic factors	Impact score	1/3	1	1	1	1/6	1/6
Environmental indicators								
Envi-1	Materials consumption	Mass & impact of consumption	1/6				1/6	0
Envi-1.1	Materials by weight	Mass of material	1/3	-1	0	0	1/6	1/6
Environmental indicators (continued)								
Envi-4.2	Waste by type and disposal method	Mass of waste generated	1/3	-1	0	0	1/6	1/6
Envi-4.3	Overall quality of waste	Impact score	1/3	1	-6	-3	0	1/3
Envi-5	Products and packaging materials reclaimed	Percentage reclaimed	1/6	1	0	0	1/12	1/12
Envi-6	Supply chain environmental impacts	Risk score	1/6	-1	6	5	0	1/6

Table A3. Cont.

ID	Name	Units	Weight	Impact	Jewellery Industry	Cat. Conv. Industry	Jewellery Industry Score	Cat. Conv. Industry Score
Social indicators								
Soci-1		Employment	1/6				4/12	8/12
Soci-1.1	Number of new employee hires	Number of employees	1/2	1	8425	1461	1/2	0
Soci-1.2	Impact of employment	Impact score	1/2	1	6	7	0	1/2
Soci-2		Health & safety risk	1/6	-1	186	18	0	1/6
Soci-3		Average hours of training for employees	1/6	1	0	0	1/12	1/12
Social indicators (continued)								
Soci-4		Human rights in whole supply chain	1/6				0	1/6
Soci-4.1	Negative impacts for labor practices in the supply chain	Risk score	1/6	-1	5	3	0	1/6
Soci-4.2	Incidents of discrimination	Risk score	1/6	-1	0	0	1/12	1/12
Soci-4.3	Significant risk of freedom of association in operations and suppliers	Risk score	1/6	-1	0	0	1/12	1/12
Soci-4.4	Significant risk of child labor in operations and suppliers	Risk score	1/6	-1	0	0	1/12	1/12
Soci-4.5	Significant risk of forced or compulsory labor in operations and suppliers	Risk score	1/6	-1	0	0	1/12	1/12
Soci-4.6	Human rights impacts in the supply chain	Risk score	1/6	-1	7	3	0	1/6
Soci-5		Negative impacts on local communities	1/6				1/12	1/12
Soci-5.1	Negative impacts on local communities	Risk score	1/3	-1	3	6	1/3	0
Soci-5.2	Risks related to corruption	Risk score	1/3	-1	0	0	1/6	1/6
Soci-5.3	Negative impacts on society in the supply chain	Risk score	1/3	-1	7	5	0	1/3
Soci-6		Health and safety impacts of products and services	1/6				1/12	1/12
Soci-6.1	Health and safety impacts of products and services	Risk score	1/2	-1	1	5	1/2	0
Soci-6.2	Sale of banned or disputed products	Risk score	1/2	-1	6	4	0	1/2

Appendix C

Table A4. Sustainable development goals (SDGs) addressed by the respective indicators in the proposed framework.

Indicator	SDGs Addressed	Indicator	SDGs Addressed	Indicator	SDGs Addressed
<i>Economic indicators</i>		<i>Economic indicators</i>		<i>Social indicators</i>	
Econ-1	2,5,7,8,9	Envi-1	6,8,12	Soci-1	5,8
Econ-2	13	Envi-2	7,8,12,13	Soci-2	3,8
Econ-3	1,2,3,8,10,17	Envi-3	3,12,13,14,15	Soci-3	4,5,8
Econ-4	12	Envi-4	3,6,12,14	Soci-4	5,8,16
Econ-5	8	Envi-5	8,12	Soci-5	1,2,16
Econ-6	9	Envi-6	None	Soci-6	None

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4.3 Conclusion: Chapter 4

This chapter builds on the previous chapter (Chapter 3) where the leading sustainability disclosure frameworks were evaluated for their potential to be leveraged to support the evaluation of development sectors. This chapter explores the use of the GRI G4 sustainability reporting guidelines (identified in the previous chapter as holding particular promise) as a foundation for such a framework. The industry evaluation framework based on the GRI G4 framework is tested on the case of platinum beneficiation in South Africa. Reflecting on the results, it is suggested that despite clearly being useful, the framework's potential is still hampered by the constraints inherent in the data being used (e.g. that data is only available for existing companies, that the data may not be available at the product level and that the data may be biased due to various reasons). It is envisioned that some of these constraints may be overcome as sustainability disclosures continue to be improved in future. Given the shortcomings of the developed framework, the following chapter explores another avenue towards the assessment of the strategic potential of developmental industries.

Chapter 5

The input-output product space approach for strategic industry identification

This chapter is the third of three chapters that aim to address the second objective of this research, namely to “develop new/adapted analytical frameworks that provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities”. It is distinct from the other two chapters as it focusses on the use of the product space as a foundation for the assessment of the strategic value of development industries (as opposed to sustainability disclosures). This chapter consists of three sections. The first (Section 5.1) situates the chapter within the narrative of the dissertation (as summarised in Figure 5.1). The second section (Section 5.2) contains the article which comprises the primary part of this chapter. Finally, Section 5.3 concludes the chapter by summarising its contribution to the dissertation.

5.1 Introduction:Chapter 5

The previous two chapters (Chapter 3 and 4) presented a framework towards the attainment of the second objective of this research. This chapter presents another framework that aims to achieve the same aim but from a different perspective. In particular, this chapter uses the product space concept (developed by Hidalgo *et al.* (2007)) as a foundation to evaluate the strategic value of different downstream processing activities in order to prioritise policy attention and to derive an appreciation of the possible advantages of attaining a particular processing industry. The chapter also uses this framework to derive insights regarding the theoretical debates surrounding beneficiation policy, based on the case of steel in South Africa. In particular, the results from the case study seem to suggest that a “leap-frogging” approach to industrial policy

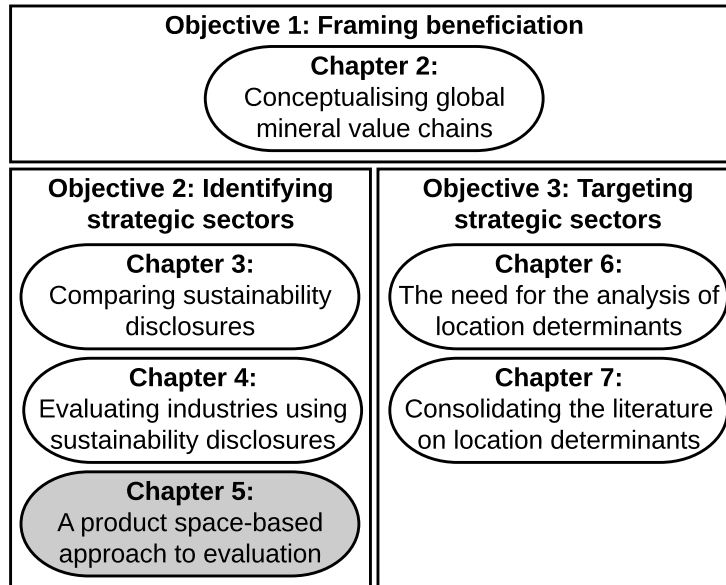


Figure 5.1: Position of Chapter 5 in dissertation.

may be more optimal than a strict beneficiation-based industrial policy logic.

5.2 Article: “Improving industrial policy intervention: the case of steel in South Africa”

The version of the article included here is the authors’ accepted manuscript version of a peer-reviewed article published as the version of record in *The Journal of Development Studies* © 2018, republished by permission of Informa UK Limited, trading as Taylor & Francis Group, <https://doi.org/10.1080/00220388.2018.1528354>. The online version of the article includes freely downloadable supplemental material. This material includes the Matlab code and trade code mappings used for the analyses presented in the article, as well as additional background literature. A popular press version of the article was published on *The Conversation* platform and is available at: <https://theconversation.com/beneficiation-is-touted-as-a-silver-bullet-why-it-might-not-be-110224>.

Improving industrial policy intervention: the case of steel in South Africa

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Abstract:

We contribute to the lack of tools to support efficient industrial policy-making, especially in the mineral beneficiation policy literature. To address this vacuum, we adapt the product space analysis approach to incorporate an input-output value chain lens. This framework is applied to the case of steel in South Africa to derive novel insights regarding the (in)efficiency of implementing a downstream linkage-based beneficiation policy. Our dynamic analysis approach allows for interactions with the rest of the product space. We find that a “leap-frogging” approach to development within the value chain may be more optimal than a strict beneficiation based industrial policy.

Introduction

For decades, globalization was considered necessary and sufficient to drive development. Recently, an increasing trend towards re-acknowledging the role that government intervention, and industrial policy in particular, can and should play in supporting the development of countries has emerged (Chang, 2003; Cimoli, Dosi, & Stiglitz, 2009; Horner, 2017). This narrative suggests that policies should target the market failures that restrict growthⁱ, which developing countries in particular are faced with (Hausmann & Rodrik, 2006). These policies might be horizontally (economy wide) or vertically (sectorally) targeted (Spring, Hughes, Mason, & McCaffrey, 2017). Without neglecting the importance and complementarity of both policy types, the focus here is on vertical industrial policy decision-making.

Government intervention in the development of countries has been emphasized by a diversity of works. These range in terms of level of analysis from global (Barrientos & Smith, 2007) to regional (Peck, Connolly, Durnin, & Jackson, 2013) and community level (Rolfe, 2013). Secondly, their foci vary from economic considerations (including economic growth (Chang, 1993), inequality (Piketty & Saez, 2006) and job creation (Hilson & McQuilken, 2014)), social considerations (including labour conditions (Barrientos & Smith, 2007), skills development (Ramirez & Rainbird, 2010) and health (Calderon, Harris, & Kirsch, 2016)), environmental considerations (including addressing the loss of fauna and pollution (Anejionu, Ahiaramunnah, & Nri-ezedi, 2015)) and the integration of these concerns (through concepts such as the triple bottom line of sustainability (Allwood, Laursen, Russell, de Rodríguez, & Bocken, 2008; Du Plessis & Bam, 2018)).

This diversity underlines the multitude of factors relevant to the industrial policy-making process. Tackling all these objectives concurrently is beyond the scope of this paper. Instead, we focus on one of these - national economic growth.

One challenge to policy-making is the lack of efficient tools to support improved decision-making. This is especially relevant with regards to identifying industries that a country can and should support, as countries are indeed ‘doomed to choose’ certain sectors over others (Hausmann & Rodrik, 2006). Given the vacuum of appropriate tools, policy makers are forced to revert to intuitive approaches that potentially lead to sub-optimal results. A key example of such an approach that has delivered mixed results is the policy of beneficiation (Morris et al. 2012). This refers to mineral producing countries aiming to “capture more value” from their mineral resources by encouraging (or even forcing) the downstream value added to minerals before export (Bam & De Bruyne, 2017).

We aim to contribute to the growing literature that seeks to provide better tools for guiding industrial policy-making along various dimensions to address this vacuum. Specifically, our study is positioned within the capability theory literature. This implies that we focus our analysis on the contribution that the development of particular export industries can make to the development of a country’s economic capabilities to support future economic growth at a national level. This is particularly relevant, as developing countries can become caught in a quiescence trap if they do not continually develop capabilities that support the production and export of more complex products (Hausmann & Hidalgo, 2011).

In this paper, we extend the existing product space approach to the analysis of

input-output defined value chains. Our input-output product space (IO-PS) framework has the potential to better support countries (developing countries in particular) to develop more nuanced industrial policy. The framework seeks to support the targeting of industries that complement countries' existing production structures in order to improve developmental pathways. We highlight the utility of the framework by applying it to a mineral value chain in a developing country. As such, we are able to contrast our results with those that would be obtained if a downstream linkage-based beneficiation-type industrial policy had been followed. We thus specifically contribute not only to the industrial policy literature related to the product space approach, but to the literature concerned with the debate regarding the merits of following a beneficiation approach to industrial policy as well. The remainder of the paper is arranged as follows: the next section links our paper to the existing literature; Section 3 describes the data and methodology, while Section 4 discusses the results. Section 5 concludes the paper.

Theoretical background

As background to the paper, we consider three strands of literature: the product space literature; the literature on mapping industry input-output relations; and the literature regarding the (in)effectiveness of beneficiation. In the product space section, we provide a brief description of the metrics relevant to this study. Details on how the product space metrics are calculated, and additional background information are provided in the supplementary material.

Product space

The *product space* concept introduced by Hidalgo et al. (2007), is underpinned by the concepts of *proximity* and *revealed comparative advantage* (RCA). Most work on the

product space, including the seminal work by Hidalgo et al. (2007), employ the Balassa (1965) definition of RCA. In this definition, the $RCA_{c,i}$ is the ratio of the export of a given product i from a country c as a portion of the total exports of that country, to the global value of export of that product as a portion of total world exports.

Hidalgo et al. (2007) define RCA_{x_i} for a country c , as equal to 1 when $RCA_{c,i} > 1$ and RCA_{x_i} for a country c , as equal to 0 when $RCA_{c,i} \leq 1$. The value of 1 is thus assigned when a country can be considered to have a revealed comparative advantage in product i and 0 if it cannot. Using this restated definition, they define the concept of *proximity*, where proximity between two products (i and j) is a measure of the probability that a country will have an RCA in a product i if it also has an RCA in a product j or vice versa, whichever is the minimum. If all countries that produce the product i also produce the product j , their proximity will be equal to 1. If no country produces both products, the proximity of the products will be 0.

Using these proximity values, Hidalgo et al. (2007) visualize what they call the product space by calculating and plotting the maximum spanning tree of the product proximities and superposing the links between products where the proximity between these products is above a certain threshold. From the resulting network, it is clear that certain products can be considered to be in the *periphery* and others in the *core* of the product space. Referring to *capability theory*, products in the periphery can be considered to require capabilities that do not enable the countries that produce them to produce many other products (Hidalgo & Hausmann, 2009). For example, producing cork (located in the periphery of the product space) does not require capabilities that support the production of many other products. In contrast, competitively exporting vehicles (located in the core of the product space) is likely to lead to capabilities that could support the

production of a variety of other products such as piston engines and automotive related parts; laboratory related equipment or even boilers and related products – all products that have a relatively high proximity to vehicles. In general, the core is formed by metal products, machinery and chemicals, while the periphery is formed by agricultural, fishing, mining and extractive activities (Felipe, Kumar, Abdon, & Bacate, 2012; Hidalgo & Hausmann, 2009).

Distance is a metric that describes the position of a country in the product space relative to some product j for which it does not yet have an RCA. In particular, it is the ratio of the sum of proximities between product j and all the products for which a country has an RCA to the sum of proximities between product j and all the products in the product space. Thus, if a country has a large distance to some product j , this implies that it does not have an RCA in many of the proximate products to product j and it could be expected that it would be more difficult to acquire an RCA for it than for some product with a smaller distance value (Hausmann et al., 2011).

Two further central metrics in the product space literature are the *product complexity index* (PCI) and *country economic complexity index* (ECI). Hidalgo & Hausmann (2009) showed that such complexities can be calculated iteratively through the *method of reflections*. In this method, product complexity is a function of the complexity of the countries that produce it and the country complexity is function of the complexity of the products that it produces. These metrics are endogenous, correct for population size and are able to predict economic growth. This makes it useful for identifying products that can support development (Felipe et al., 2012; Hausmann & Klinger, 2009; Hidalgo & Hausmann, 2009).

Despite the availability of competing metrics (as described in the supplementary material), we use the original economic complexity index developed by Hidalgo &

Hausmann (2009) as it is the most established metric and has been shown to be robust and near optimal (Albeaik, Kaltenberg, Alsaleh, & Hidalgo, 2017b; Mariani, Vidmer, Medo, & Zhang, 2015; Pugliese, Zaccaria, & Pietronero, 2016).

Two other metrics for evaluating the strategic importance of development opportunities are the *opportunity value* and *opportunity gain*, described in Hausmann et al. (2011). The opportunity value of a country is a function of the product of the complement of distance to all products for which it does not have an RCA and the complexity of these products. Thus, a high opportunity value of a country implies that the products with low distances for that country generally have high complexity values. Opportunity gain, then, provides an indication of how much the attainment of an RCA in a specific product for which a country does not yet have an RCA, will contribute towards increasing that country's opportunity value.

Input-output relations

Various fields of literature resort to conceptualizations of supply chains. These include development studies, management, economics and supply chain management. Supply chains, in this context, can be viewed as sequential activities by distinct firms that transform inputs to outputs that again act as input to downstream activities, which eventually satisfy some final demand (Henderson et al. 2002). Much cross pollination between these fields has taken place (and has even been advocated for (Holweg & Helo, 2014)). Regardless, such studies can be classified into various schools of thought, each with their own collection of tools and terminology. In the development literature, much attention has recently been focused on the “global value chain” analysis (Gereffi et al. 2005) and “global production network” (Henderson et al., 2002) frameworks. In the management literature, the value chain definition of Porter (1985) has been of great

importance in establishing the term. In different fields of economics, the work of Hirschman (1981) and Leontief (1936) both established different conceptual approaches to supply chain analysis. Even within supply chain management, various conceptualizations of the supply chain exist depending on the application. These include the closed-loop supply chain (Seuring, 2013) and the international manufacturing network (Rudberg & Olhager, 2003). We draw upon the simple structure that underpins most of this research, namely, the conceptualization of different nodes that are connected through input-output relationships. We employ this structure as it allows to understand how economies transform various inputs and raw materials into final goods. In our terminology, we use the term *value* to highlight the focus of identifying the value capture that activities imply (similar to Bam & Schutte, 2017 and Henderson et al., 2002). We use the term *chain* to highlight the input-output relations between products when considered from a beneficiation perspective.

Beneficiation

Beneficiation can be broadly defined as the local value add to mineral-based products within a country before export (Department: Mineral Resources, 2011). The term is often employed in discussions regarding the merits of developing mineral producing countries further processing their extracted resources before export. In academia, this is often framed in the context of the “downstream linkages” that can be attained from mining activities as defined by Hirschman (1981) (Morris et al., 2012).

The debate regarding the merits of the policy of seeking to further process minerals in the extracting country for socio-political reasons is not new (Radetzki, 1977). A 1984 United Nations (UN) study on “Mineral Processing in Developing Countries” (United Nations, 1984) examined “the factors which affect the location of mineral

processing in developing countries”. The argument for this was that developing countries produce a large percentage of minerals but are not largely involved in the processing thereof to final products. Therefore, they could better diversify their economies, industrialize, reduce their dependence on industrial countries, develop transferable skills and increase economic rents by processing their minerals themselves. The same study (and authors such as Crowson, 2008) explore some of the many reasons why such beneficiation might be difficult (and very costly) to achieve. Regardless, in the 2000’s, the resource boom again saw an increase in beneficiation policies being implemented and considered by a variety of countries (Bam & De Bruyne, 2017). Despite the clear interest of governments in implementing beneficiation policies, some authors have completely rejected beneficiation as a basis for policy making (Hausmann et al. 2008). Despite these diverging views, the emerging consensus appears to be that there is a place for beneficiation-based policy, but that it is not advisable across the board. Rather, opportunities should be very carefully evaluated. Consequently, there is a sustained call in the literature for a more nuanced approach in dealing with opportunities for beneficiation (Bocoum-Kaberuka, 1999; Ivanova, 2014; Morris & Fessehaie, 2014; Morris et al., 2012; Reinhardt, 2000). Overall, the analytical tools available for guiding such policy are still lacking. We thus aim to specifically address this gap in the beneficiation literature by proposing a novel analysis approach to answering this question from a product space perspective. In particular, we aim to provide a complementary perspective to the existing global value chain and linkage-based approaches most commonly applied in the debate (Bam & De Bruyne, 2017).

Data and methodology

The data used for this study was downloaded from the MIT Observatory for Economic Complexity (OEC) website (<https://atlas.media.mit.edu/en/resources/data/>). In particular, the HS6 1992 Revision data at 4-digit depth was used, which the OEC sourced from the BACI International Trade Database. The MATLAB code used for the analysis of the data is available in the supplementary material of this article.

Our methodology consists of three phases. First, a suitable case was selected (discussed in Section 3.1). Second, we constructed a novel, granular input-output map of the industry (discussed in Section 3.2). This not only enabled the evaluation of the industry from an input-output value chain perspective, but also required the definition of product categories that consist of products directly linked to international trade codes. This was necessary to enable the application of a product space perspective. The final phase of the methodology entailed a detailed product space driven analysis of the focal country and value chain (discussed in Section 3.3). The application of this input-output product space (IO-PS) framework to a representative mineral value chain case study provides a new perspective on the beneficiation debate.

Case selection

Four aspects were considered in the selection of a case study country. Subsequently, South Africa was chosen as the ideal candidate. Firstly, due to the focus of the study, the country was required to be a developing country – a country with a relatively low complexity value (South Africa has a negative economic complexity, -0.3 (OEC 2017)). This ensured that the country could be expected to have a relatively small footprintⁱⁱ of complex products in the product space – enabling simulations of the attainment of new, more complex products. Secondly, given the focus on beneficiation, mineral resources

had to constitute an important part of the country's exports (mineral and precious metals exports accounted for 33% of South African exports in 2016 (OEC, 2017)). Thirdly, the country needed to have sufficient data quality and availability for analysis (South Africa is included in UN COMTRADE, The Center for International Data and the BACI International Trade Databases). Finally, the country must have considered beneficiation policy in the past, making the case study results directly applicable to the beneficiation debate (South Africa's Department of Mineral Resources (DMR) has published a "Beneficiation Strategy" aiming to provide a blueprint toward increasing beneficiation in the country (Department: Mineral Resources, 2011))

Four further aspects were considered to select a suitable mineral value chain for analysis, resulting in the selection of the steel value chain. Firstly, South Africa would need to have an RCA in the production of the mineral (South Africa's RCA for iron ore is 7.58). Secondly, South Africa must not yet have an RCA for the entire value chain (South Africa has an $RCA > 1$ in only 39 of 272 products that can be considered part of the steel value chain). Third, the value chain should on average have a relatively high complexity in order to ensure that it is worth pursuing from a development perspective (average complexity of products in the steel value chain is 0.61 - substantially above the complexity of South Africa). Fourth, the industry should have a relatively large international trade value to ensure the industry is internationally important and relevant (products considered part of the steel value chain had a global export value of US\$7 118 billion in 2014, accounting for 40% of global exports). Finally, the industry should ideally have been identified by the South African government as an industry of interest, in order to ensure the maximum relevance of the results (the steel industry is and has in the past number of years been directly and indirectly targeted as part of the South African government's "Industrial Policy Action Plan" (Department: Trade and Industry, 2017)).

The case is of further interest as the success of industrial policy at large in South Africa has at best been mixed. The Motor Industry Development Program for instance (deemed by some to be one of the most successful examples) has been assessed both positively (Barnes, Kaplinsky, & Morris, 2004) and negatively (Barnes et al., 2004) as it has increased productivity and exports but import tariffs on finished vehicles remain high, implying high costs for consumers. Secondly, the Department of Trade and Industry is very much in favour of beneficiation especially in the metals and minerals sector. However, Hausmann, Rodrik, & Sabel (2008) highlight the possible dangers for South Africa of following a classic beneficiation approach. This highlights the need for additional studies to better guide the government's beneficiation strategy and the direct policy relevance of the chosen case.

Industry value chain mapping

In the second phase of the methodology, a novel trade-code based input-output mapping was constructed through a multi-step mapping process. In the first step, the US Bureau of Economic Analysis input-output as well as make and use tables from 2002 were used. These provided a foundation for identifying the industries that are linked through value chain input-output relationships with iron ore, iron and steel. Using concordance tables, these were then converted to HS trade codes. These mappings were further refined to identify product categories – each representing up to 11 four digit HS trade codes (detailed in Table S1 in the supplementary material to this paper) – using detailed industry mappings (Cullen et al. 2012). The product categories were chosen in order to represent related product groups which could be collectively targeted by sectoral government intervention. Based on the resulting mapping, all excluded 2-digit HS trade codes were evaluated to determine whether any had an average proximity to the value chain higher

than the average proximity of those already included. Based on these calculations, HS 76 – aluminium and articles thereof – was also included in the mapping. The categories were then divided into tiers based on their input-output relations. Thus, tier n category products consume products in tier n-1 during production. The resultant industry map was further fine-tuned and validated through discussions with industry experts. The validated mapping provided the foundation for the rest of the analysis.

Country specific analysis

Using the derived input-output mapping, country specific analyses for South Africa could be performed and an IO-PS analysis framework developed. The resulting framework and results are discussed in detail in the following section. The approach focusses on products within each product category for which the country does not yet have an RCA. Three specific metrics were deemed important, namely: i) complexity (due to its importance for understanding the product category's potential contribution to economic growth); ii) distance (as it provides an indication of how difficult it would be to attain the products within a product category from a government perspective); and iii) opportunity gain (as it provides an indication of how much the attainment of products within a specific product category could contribute towards the development of capabilities that could support the attainment of other high complexity products in the future).

Results and discussion

Combining our granular mapping with metrics from the product space literature, it is possible to indicate the worldwide (i) complexities of each product categoryⁱⁱⁱ; and (ii) bilateral proximity values larger than or equal to 0.4^{iv} as shown in Figure 1.

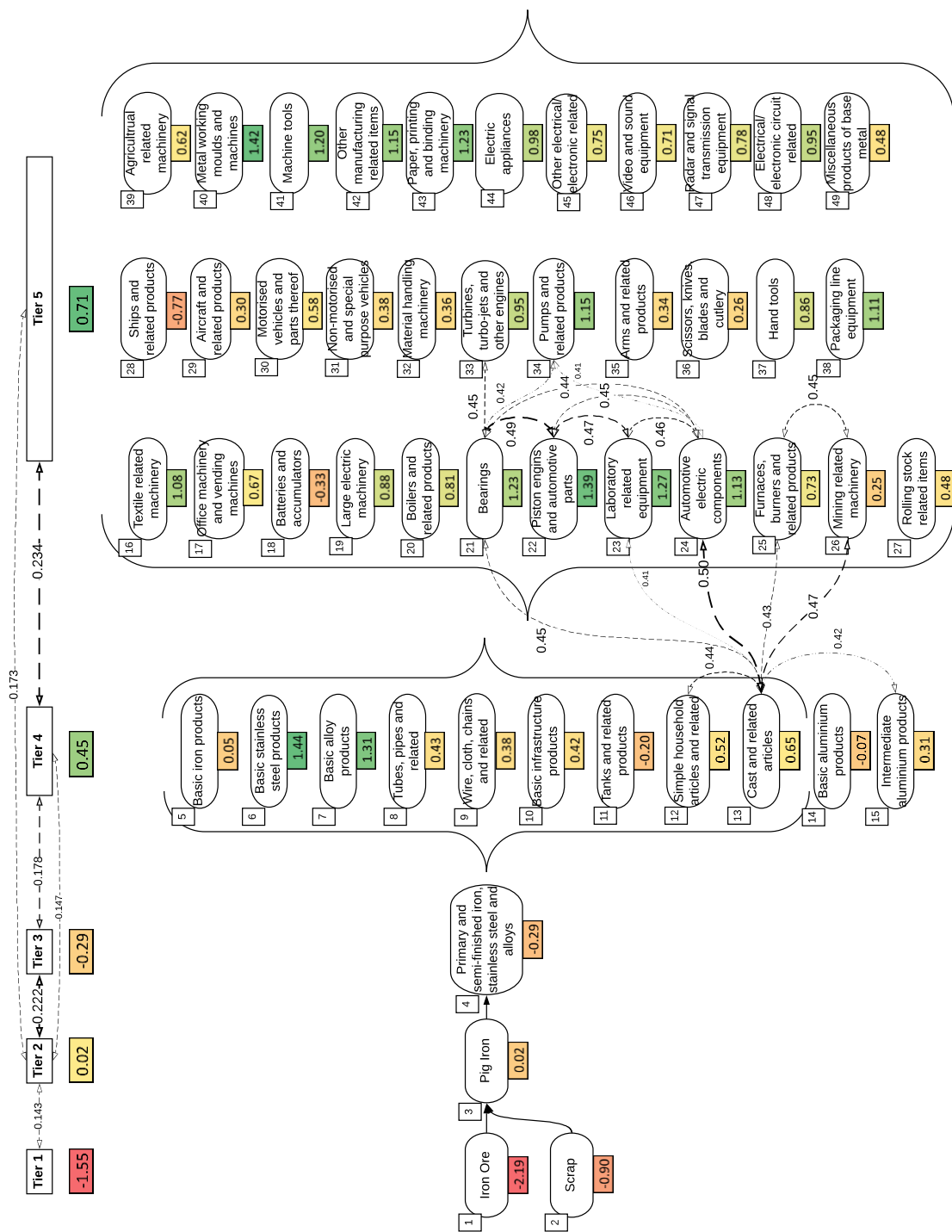


Figure 1: Aggregated (tier-level) and products category level steel value chain with global complexity scores and high proximity values.

In Figure 1 and throughout the remainder of the text, we use colour coding to ease the interpretation of results. In each case, the values are coloured on a spectrum ranging from red (least desirable from the perspective of a government seeking to intervene in industry), orange and yellow to green (most desirable^v). When the aggregated tier-level metrics in Figure 1 are evaluated, they seem to broadly support the classic beneficiation narrative. The downstream tiers have higher average complexities and the highest proximities between tiers are between those that are adjacent. However, tier 1 – iron ore and scrap – is least proximate to the rest of the value chain, again highlighting the difficulty of diversification and beneficiation that many mineral resource countries face. Intuitively, it seems that the logic of targeting input-output linked products in order to move downstream is justified – particularly if the gap from tier 1 to tier 2 can be bridged. However, if the product category level is considered, it is clear that the picture is more complicated. For example, category 28 in tier 5 has a lower complexity than the tier 2 product category. Clearly, selection of which product category/-ies to target at the disaggregated level is significantly more challenging than apparent at the tier level. As a further example, based on Figure 1 (without considering a country's current footprint), one might argue that targeting product categories 6 and 40 makes most sense from a complexity point of view. However, if the proximities are considered, product categories 22 and 23 (with slightly smaller complexities) are better connected to other product categories in the value chain. It thus appears to be advisable to target product categories 6 (basic stainless-steel products) and 40 (metal working moulds and machines) when one is mainly focused on the short-run outcome (maximizing complexity) and target product categories 22 (piston engines and automotive related parts) and 23 (laboratory related equipment) when the long-run impact on other product categories is taken into account as well (maximizing opportunity gain). This very simple and intuitive example using

generic industry data already provides important insights, but still omits many aspects relevant to gaining a nuanced understanding of implications for countries considering following a beneficiation approach to diversification.

Therefore, we propose a more detailed, country specific IO-PS analysis, which adds another dimension to the above analysis by extending it on three fronts. First of all, the extended framework considers the footprint of the focal country, instead of studying the value chain at a generic *worldwide* level. Industrial policy at *country* level needs to take into account which product categories within the country are already performing well – have a large share of their products with an $RCA > 1$. The current footprint will determine the difficulty of attaining the remaining products in any given category. For example, acquiring the remainder of the products in categories for which the average $RCA > 1$, may be easier to achieve and therefore unlock other product categories at a lower cost. Second, in order to keep Figure 1 tractable, only the highest proximity values were indicated. One might therefore miss out on selecting product categories that unlock other product categories (within or outside of the focal value chain) through proximities that are not shown in the figure. We use the product space metric of opportunity gain to consider the unlocking of future opportunity throughout the entire product space. Finally, as Figure 1 only considers the proximity of products to other products in the value chain, it ignores the fact that having an RCA in products in other value chains may also reduce the difficulty of attaining products within a product category in the steel value chain due to requiring related capabilities. Thus, we also add the consideration of distance from an entire product space perspective.

Considering the case of steel in South Africa using these three extensions, the beneficiation narrative again seems to be further strengthened when the tier-level case specific metrics are evaluated (Table 1).

Table 1: Case specific (South-African) metrics aggregated at tier level.

<u>Tier#</u>	<u>Avg. RCA</u>	<u>Avg. complexity for products with RCA <1</u>	<u>Avg. distance for products with RCA <1</u>	<u>Avg. opportunity gain for products with RCA <1</u>
1	5.18	N/A	N/A	N/A
2	6.23	N/A	N/A	N/A
3	4.46	0.60	0.827	0.20
4	0.85	0.49	0.830	0.19
5	0.53	0.77	0.845	0.26

It is clear that South Africa is relatively competitive in the first three tiers of the value chain, but not further downstream^{vi}. Furthermore, Table 1 indicates the average complexity of, distance to and opportunity gain of the underlying products within each tier for which South Africa does not yet have an RCA. From the metrics in Table 1, it is clear that the further downstream products have higher distances, but also higher opportunity gains and complexities. Products further downstream can thus be expected to better support economic growth, but it appears to be more difficult to competitively export these products given the current capabilities of South Africa.

Table 1 is where the beneficiation debate generally ends: from the point of view of complexity, it is a good idea to go as far down the value chain as possible but from the point of view of distance, going further down the value chain appears to be difficult. Using the extended country specific metrics, we perform 2 further analyses. First, we add a *more granular* analysis to the case study (analysing the product category level); and secondly, we add a *dynamic* analysis to evaluate the distance; complexity; and

opportunity gain trade-offs that countries need to consider when targeting development opportunities under both shorter-term and longer-term strategies.

By simply eye-balling the more granular (static) analysis data (Table 2), we can point out several product categories that would not be primarily targeted if a beneficiation approach were to be taken.

Table 2: Metrics for South Africa at the product category level

<u>Product Category #</u>	<u>Avg RCA</u>	<u>Avg. complexity of products within the VC if all products in category have a RCA > 1</u>	<u>Opportunity gain if all products in category have RCA > 1</u>	<u>Sum of distances to products in category</u>
Baseline		-0.009		
Tier 1				
1	7.58	N/A	N/A	N/A
2	2.79	N/A	N/A	N/A
Tier 2				
3	6.23	N/A	N/A	N/A
Tier 3				
4	4.46	0.034	0.32	2.48
Tier 4				
5	0.80	0.003	0.65	5.68
6	1.02	0.096	0.57	2.54
7	0.10	0.140	1.02	4.25
8	0.35	0.040	0.54	4.14
9	1.55	0.071	0.77	4.21
10	0.93	0.012	0.36	1.67
11	1.01	-0.023	0.02	0.80
12	0.23	0.039	0.27	3.35
13	0.57	0.023	0.19	1.66
14	1.05	-0.028	0.10	1.60
15	0.98	0.040	0.58	7.43

<u>Product Category #</u>	<u>Avg RCA</u>	<u>Avg. complexity of products within the VC if all products in category have a RCA > 1</u>	<u>Opportunity gain if all products in category have RCA > 1</u>	<u>Sum of distances to products in category</u>
Baseline		-0.009		
Tier 5				
16	0.15	0.213	1.67	8.62
17	0.18	0.081	0.63	5.15
18	0.24	-0.025	0.24	1.66
19	0.22	0.092	0.74	4.24
20	0.22	0.116	0.92	5.87
21	0.22	0.022	0.21	0.85
22	0.59	0.177	1.20	5.05
23	1.92	0.052	0.44	1.68
24	0.19	0.046	0.38	1.69
25	0.49	0.027	0.29	1.67
26	3.37	N/A	N/A	N/A
27	1.12	0.100	0.90	5.05
28	1.78	-0.099	0.50	3.96
29	2.61	0.015	0.56	2.48
30	0.86	0.080	0.79	4.96
31	0.50	0.050	0.73	5.95
32	0.58	0.054	1.06	6.59
33	0.40	0.059	0.48	2.51
34	0.37	0.099	0.61	3.39
35	0.30	0.035	0.77	4.99
36	0.12	0.022	0.44	4.27
37	0.44	0.168	1.65	8.52
38	0.36	0.045	0.35	1.72
39	0.55	0.125	1.12	7.50
40	0.41	0.111	0.66	2.57
41	0.13	0.217	1.67	7.69
42	0.39	0.099	0.85	3.38
43	0.23	0.106	0.80	3.40
44	0.19	0.159	1.05	6.85
45	0.29	0.106	0.92	5.93
46	0.08	0.101	0.75	6.03
47	0.33	0.110	0.75	5.99
48	0.16	0.187	1.26	8.52
49	0.47	0.096	0.92	7.59

The first column of Table 2 indicates the average RCA for each product category: the higher its value, the more products within that product category already have an $RCA > 1$ and/or the higher the RCA of the products for which the $RCA > 1$. The following two columns indicate the average complexity of products in the value chain and total opportunity gain if the product category would be successfully targeted – if the RCA for all products within the product category were rendered higher than 1. Given the fact that the initial value for the average complexity for South Africa is -0.009, the successful targeting of (almost all)^{vii} product groups would increase the average complexity of products within the value chain. Finally, the last column shows the sum of distances to the products in each product category given the current production structure. A higher distance value implies more products and/or more distant products with an $RCA < 1$ within a product category. What can be observed from these metrics is that even though, in general, the distance to products further downstream is higher, the distances to some of the downstream product categories are not. This would suggest that instead of systematically following a beneficiation strategy of first developing the capabilities of competitively producing further upstream products before producing downstream products, South Africa can already target specific downstream activities that should be equally attainable, if not more attainable, and will likely contribute more towards economic development. Thus, the optimal route would imply a sort of “leap-frogging” when viewed from an input-output perspective.

More in particular, columns 3 and 5 of Table 2 show us that product categories 11 and 21 are easy to obtain^{viii} from a distance point of view but targeting them is not strategic from a complexity point of view. Targeting product categories 16, 22 and 41 makes more sense from a complexity point of view but given their higher distances, targeting these product categories would likely require more drastic interventions. When

taking a longer-term view, it also becomes important to understand which other product(s) within the product space become unlocked by selecting particular product categories. Column 4 provides a first indication: product categories 16 and 41 for instance increase the opportunity gain more than product category 22.

To further investigate the robustness of these initial findings, we introduce a dynamic analysis to evaluate which of these product categories should be targeted preferably. In the dynamic analysis, we also make a distinction between a shorter-term targeting strategy – focusing on maximizing complexity – and a longer term targeting strategy – focusing on maximizing opportunity gain. In other words, instead of merely picking the next ‘logical’ product category suggested by the beneficiation literature based on input-output relations, we allow for the possibility to target that/those product category/-ies in the value chain that maximize either complexity or opportunity gain^{ix} given different distance scenarios. In our model, the distance that a country is able to traverse is kept constant under the different strategic regimes. Within this confine, the country seeks to maximize the chosen goal metric by attaining one or more product categories (limited to a maximum of three^x) that collectively constitute a cumulative distance that is smaller than or equal to the chosen distance constraint, after controlling for the changes in values after the products in each product category are attained. The results from the simulations are indicated in Table 3 (complexity maximizing) and Table 4 (opportunity gain maximizing).

Table 3: Model results for complexity maximizing case

Complexity maximising						
Distance constraint	Distance used	Product Category 1	Product Category 2	Product Category 3	Average complexity of products within the value chain with RCA >1	Total opportunity gain (considering entire product space)
INITIAL METRICS					-0.009	N/A
1	0.85	21	0	0	0.022	0.209
3	2.57	40	0	0	0.111	0.664
5	4.25	23	40	0	0.162	1.073
7	6.78	6	40	23	0.245	1.558
9	8.44	40	21	22	0.291	1.956
11	10.98	22	43	40	0.344	2.461
13	11.82	7	22	40	0.369	2.621
15	14.41	7	40	41	0.393	2.961
17	16.85	7	22	41	0.429	3.420
19	18.71	16	40	41	0.430	3.383
21	20.38	7	16	41	0.441	3.726
23	21.15	22	16	41	0.462	3.884
25	21.15	22	16	41	0.462	3.884
27	21.15	22	16	41	0.462	3.884

Table 4: Model results for opportunity gain maximizing case

Opportunity gain maximising						
Distance constraint	Distance used	Product Category 1	Product Category 2	Product Category 3	Average complexity of products within the value chain with RCA >1	Total opportunity gain (considering entire product space)
INITIAL METRICS					-0.009	N/A
1	0.85	21	0	0	0.022	0.209
3	2.57	40	0	0	0.111	0.664
5	4.99	10	21	29	0.061	1.127
7	6.80	40	42	21	0.223	1.646
9	8.41	40	42	29	0.209	2.000
11	10.95	22	40	42	0.339	2.496
13	12.62	7	22	42	0.355	2.790
15	14.38	7	41	29	0.321	3.032
17	16.85	7	22	41	0.429	3.420
19	18.63	41	37	29	0.328	3.550
21	20.27	7	41	37	0.406	3.769
23	21.99	22	16	37	0.421	3.968
25	24.59	16	41	37	0.438	4.185
27	24.59	16	41	37	0.438	4.185

In each table, we determine i) the (sequence of) targeted product categories for fixed distance constraints (and the distance use this sequence implies); ii) the resultant average complexity of products within the value chain; and iii) the opportunity gain within the product space. The distance constraints are derived from the frequency distribution of the average distances of products in each of the product categories in the steel value chain to the rest of the product space. It turns out that 6 of the 49 product categories have an average distance less than 1 (with four having a distance of 0, as they have no products for which the $RCA < 1$). The furthest product category has a distance of 8.62. Thus, the maximum distance scenario was set at 27 in order to ensure that any product category combination could be considered for inclusion in the final scenario, given that up to 3 product categories were considered. By allowing the distance to gradually increase between 1 and 27, we are able to study how the optimal combination of products varies depending on the appetite for targeting product categories with higher distances. At the top of each table, we also include the initial metrics so as to compare the scenarios with the initial situation.

Table 3 illustrates the results when product categories are targeted based on their complexities. Clearly, if a larger distance can be traversed, more goods and/or goods of higher complexity will be targeted, therefore increasing the average complexity in the value chain. This clearly also increases the total opportunity gain by unlocking more goods and reducing the average distance to other products. If a more conservative scenario (with a smaller distance) is aimed for, our results suggest targeting (different combinations of) product categories 21 (bearings), 40 (metal working moulds and machines), 23 (laboratory related equipment) and 6 (basic stainless-steel products). The sum of distances to products within these product categories is relatively low – rendering them reachable at low distances – and they increase the complexity moderately. Under

more ambitious scenarios (with greater distance requirements), targeting the more complex product categories 7 (basic alloy products) and/or 22 (piston engines and automotive related parts) also become viable. Finally, product categories 16 (textile related machinery) and 41 (machine tools) are only considered under very ambitious scenarios since the sum of the distances to products in these two product categories is very high. As long as the distance constraint is at least 21.15 and a maximum of three product categories can be targeted, the optimal combination is 22, 16 and 41. Increasing the distance threshold further will not alter the optimal combination of these three product categories. Together, they increase the complexity the most^{xi}. On a final note, our complexity maximization never suggests targeting product category 37 (hand tools and related) or 48 (electrical circuit components) while these product categories also have a high complexity. Even though they have high distance requirements, from the static analysis (in Table 2) they seem to unlock other goods in the product space. The obvious question then is whether maximizing complexity within the value chain is the optimal strategy. To consider the impact of rather focusing on the unlocking of other products within the (entire) product space, we move to Table 4 where the opportunity gain is maximized.

Table 4 illustrates the results when product categories are targeted based on their opportunity gain. It is again clear that, generally speaking, if a more ambitious (higher distance) strategy is followed, the product categories with the highest impact on opportunity gain will be targeted. Generally speaking, they will also be the product categories that increase the average complexity in the global value chain and decrease the average distance the most. If a more conservative approach is followed, our results suggest targeting (a combination of) product categories 21 (bearings), 40 (metal working moulds and machines), 10 (basic infrastructure and construction products), 29 (aircraft

and related products) and 42 (other tools and manufacturing items). As higher distance strategies are contemplated, targeting product categories 7 (basic alloy products), 22 (piston engines and automotive related parts) and/or 41 (machine tools) also becomes attractive. Finally, product categories 16 (textile related machinery) and 37 (hand tools and related) are only interesting candidates under very ambitious distance scenarios since the sum of distances to products in these two product categories are extremely high.

Reassuringly, we find that, generally speaking, maximizing complexity and opportunity gain often lead to the same product groups being selected. However, in focusing on the short-term complexity maximization, we could miss out on targeting product groups that lead to a higher total opportunity gain – product categories 42 (other tools and manufacturing items) and 37 (hand tools and related) are such examples. They do not only increase complexity but also unlock possibilities within the whole product space. Targeting such product categories in other words facilitates South Africa in the future to disperse its activities more (easily) towards higher complexity goods throughout the product space. Ultimately, we do not identify which product categories South Africa should tackle primarily – this indeed goes beyond the scope of this paper as it depends, amongst other factors, on both the ambitious and the strategic intent of the country (possibly including a variety of the considerations highlighted in the introduction) as well as requires an analysis of the individual factors driving the distance metrics.

Nonetheless, our IO-PS framework complements the existing value chain-based analyses of beneficiation policy in three ways. Firstly, the IO-PS framework introduces a more detailed and nuanced lens by allowing rapid quantitative analysis at the product category level (and not just the tier level). Thus, it is able to move beyond the high-level narrative emerging at the tier level and uncover the complexities that are apparent at the product category level. Yet, the results are, arguably, more convincing and intuitive than

those that have been attained through the application of the PS approach alone. Secondly, the IO-PS framework is able to consider policy strategies within a mineral value chain while efficiently considering the effect of such a strategy on the attainability of products not included in the value chain, but which might require similar capabilities (through the metric of opportunity gain). This thus extends the value chain centrality of the beneficiation literature. Finally, the IO-PS framework brings novel quantitative metrics to the analysis of input-output mappings. These quantitative metrics (distance, opportunity gain and complexity) provide a rich extension to the collection of tools that already exist to analyse such mappings towards informing policy.

These extensions enable the derivation of a key insight regarding the beneficiation policy debate. Specifically, while tier level metrics seem to support the general beneficiation narrative, the granular (product category) level seems to suggest that a “leap-frogging” approach is considerably more optimal in terms of return on investment. It thus enables not only a critique on the rationale of following a classical beneficiation policy, but also provides a framework to support improved beneficiation policy decision-making in the future.

Conclusions

In this paper, we highlighted the multiple factors that need to be considered when setting industrial policy, as well as the lack of appropriate tools to support industrial policy-making. Within this context, we used the capability theory literature (focussing on economic development and the development of strategic export sectors in particular) as a point of departure to contribute towards addressing this need. Specifically, we introduced a novel input-output product space (IO-PS) industrial policy analysis framework that allowed us to gain insights, through a case study, regarding the optimality of implementing beneficiation policy from a capability theory perspective.

The framework consists of utilizing the input-output mapping of an industry and identifying product categories. For each of these categories, product space metrics relevant to industrial policy setting are calculated. These metrics include i) distance (providing an indication of the likely difficulty of establishing the competitive production of the relevant products); ii) complexity (indicating the contribution of products to income growth) and; iii) opportunity gain (providing an assessment of the value of the capabilities that will be developed for unlocking future opportunities – both within the focal value chain and the rest of the product space). These metrics are used in a dynamic analysis to identify optimal developmental paths under different distance constraints. We apply this framework to the question of beneficiation through a representative case study of the steel value chain in South Africa. We find that the results broadly support the beneficiation narrative when the unit of analysis is set at the value chain tier level. However, we find that when product categories are considered as the unit of analysis, it seems that a type of “leap-frogging” approach to industrial policy within mineral value chains is more optimal. We thus developed a framework which enabled a critique on strict interpretations

of beneficiation policy and which can be used to guide better industrial policy decision-making.

We see at least three opportunities for further research: firstly, investigating the link between distance and monetary (or other) investment required to attain an $RCA > 1$ in the production of a product for which the current $RCA < 1$ (this includes considering the impact of different starting RCA values instead of using – as in this research - binary values); and secondly, refining the conclusions regarding the optimal strategy for development for the case country. In particular, other value chains will also need to be considered regarding their potential to develop high complexity products with high opportunity gain at low distances. Ideally, this will be included in a dynamic analysis which considers the opportunities at a product category level in multiple value chains concurrently. Finally, the results from our approach should be complemented with analyses focussing on the other important objectives of industrial policy highlighted in the introduction in order to derive a more holistic view of the merits of targeting industries.

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- i Including self-discovery externalities, coordination externalities and missing public inputs.
 - ii A country's footprint is considered to include those products for which it has an $RCA > 1$.
 - iii The complexities are calculated as the average complexity of all products in the product category (both products with $RCA < 1$ and $RCA > 1$)
 - iv To keep the figure tractable, we only show the 1,3% (32/2352) highest proximity linkage values between product categories.
 - v For complexity and opportunity gain, higher values are deemed more desirable; for distance, lower values are.
 - vi South Africa has an RCA in all products within tier 1 and 2 and an RCA for many (not all) products within tier 3.

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- vii Exceptions are product categories 11 (tanks and related products), 14 (basic aluminium products), 18 (batteries and accumulators) and 28 (ships and related products).
- viii “Obtain” refers to achieving an $RCA > 1$ for all products within the product category.
- ix We observe that both concepts generally move in the same direction. Obtaining an RCA in a complex good generally increases the opportunity value as it tends to increase the densities to more complex goods by developing valuable capabilities. In theory, however, it may also decrease the opportunity gain if (i) the extra good itself is extremely complex (thus lowering the average complexity of goods not yet obtained) and/or (ii) the extra good does not contribute significantly to unlocking any other goods (it lowers – or at least does not increase - the average density to high complexity goods not yet obtained)
- x Ideally, no restriction should be placed on the number of product categories included in the analysis and distance should act as the only restriction. However, the number of categories was artificially limited for the practical consideration of computer running time required as it increases exponentially when an additional industry is included. The foresight of three industries was deemed to be sufficient, as various other aspects of the product space may also have changed in the time it takes to acquire three industries, justifying a rerun of the simulation.
- xi The selection of these 3 product categories is a result of a dynamic maximization process. Looking at Table 3, product category 48 seems to outperform product category 22 when the distance constraint is sufficiently relaxed. However, this is a static result and does not take the dynamics into account – i.e. the earlier selection of other product categories.

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5.3 Conclusion: Chapter 5

This chapter uses the product space concept (developed by [Hidalgo *et al.* \(2007\)](#)) as a foundation to evaluate the strategic value of different downstream processing activities in order to prioritise policy attention and to derive an appreciation of the possible advantages of attaining a particular processing industry. The chapter also uses this framework to derive insights regarding the theoretical debates surrounding beneficiation policy, based on the case of steel in South Africa. In particular, the results from the case study seem to suggest that a “leap-frogging” approach to industrial policy may be more optimal than a strict beneficiation-based industrial policy logic. This chapter concludes the part of the dissertation that seeks to address the second research objective of the dissertation, namely to “develop new/adapted analytical frameworks that provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities”. The following chapters subsequently focus on the third and final research objective of this dissertation.

Chapter 6

The importance of evaluating the drivers of location

This chapter is the first of two chapters that aim to address the third objective of this research, namely to “develop a new analytical framework that enables the appraisal of the factors driving the location of particular downstream mineral processing activities to understand how such activities could be targeted (and thus attain a first approximation of the cost and feasibility of doing so)”. This chapter focusses on providing the rationale for studying the factors that drive the location of economic activities. The chapter consists of three sections. The first (Section 6.1) situates the chapter within the narrative of the dissertation (as summarised in Figure 6.1). The second section (Section 6.2) contains the article which comprises the primary part of this chapter. Finally, Section 6.3 concludes the chapter by summarising its contribution to the dissertation.

6.1 Introduction: Chapter 6

The previous three chapters have explored approaches to evaluating the strategic value of different downstream processing activities in order to prioritise policy attention and to derive an appreciation of the possible value of attaining a particular processing industry. However, these approaches do not address whether such industries could feasibly be developed in a country and how this would be achieved. Hence, in pursuit of the third and final objective of this research, Chapters 6 and 7 explore how countries may appraise the mechanisms driving the location of a particular activity in order to understand how such an activity could be targeted and thus attain a first approximation of the cost that would be linked to such interventions. Chapter 6 considers why there is a need for understanding location determinants in order to better inform downstream mineral processing related policy. It thereby lays the foundation for the following chapter (Chapter 7) that investigates the key factors that may affect the location of economic activities in general and how these factors

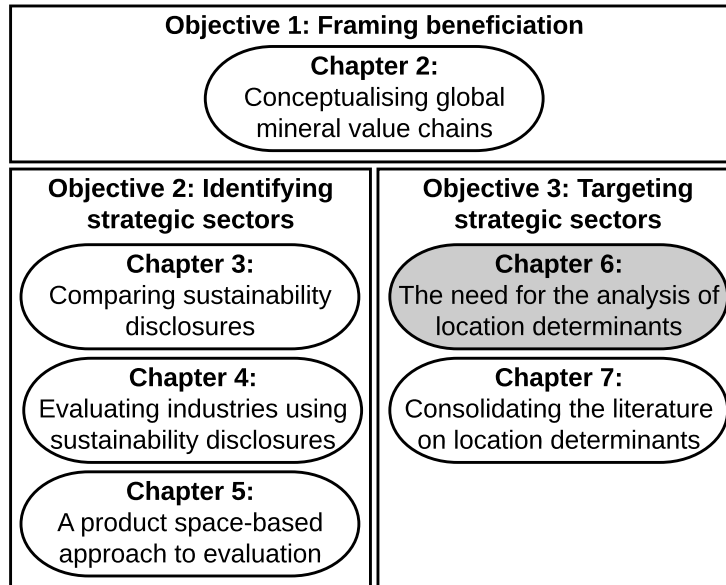
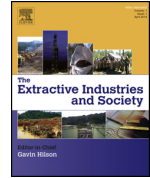


Figure 6.1: Position of Chapter 6 in dissertation.

may be combined to construct a framework that may be used to systematically evaluate the factors affecting the location of a specific activity. This enables the consideration of which mechanisms policy-makers may be able to employ to influence the location of such an activity. This chapter thus critiques the existing literature that deals with downstream mineral processing policy and highlights the need for further work in evaluating the key factors that drive the location of mineral processing activities.

6.2 Article: “Location policy and downstream mineral processing: A research agenda”

The article presented in this section is the published version of a peer-reviewed viewpoint article published in the international journal *Extractive Industries and Society*. The publication is an extended version of a presentation presented at the *Harnessing Extractive Industries for Development in sub-Saharan Africa* workshop held at the University of Surrey, Guildford, UK in June 2016. The online version of the article is available at <https://doi.org/10.1016/j.exis.2017.06.009>.



Viewpoint

Location policy and downstream mineral processing: A research agenda



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ABSTRACT

The mixed results from the recent implementation of a wave of policies that aim to encourage the downstream processing of minerals – mainly in developing countries – have highlighted the need for research to better guide and support policy-making in this area. Specifically, it is crucial to determine whether mineral producing countries can or should intervene in the processing location of minerals, and if so how to go about doing so. This paper highlights these concerns by broadening our understanding of the location determinants of downstream mineral processing. We argue that researchers must move beyond the more descriptive linkage theory and Global Value Chain (GVC) and Global Production Network (GPN) approaches to incorporate New Economic Geography (NEG) theories, to improve awareness of location decisions' determinants. A profound understanding of these determinants is imperative to determine policy measures capable of influencing location outcomes. This must be complemented with an identification and evaluation of the policy options available to mineral producing countries in order to attract – or maintain – downstream processing.

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1. Introduction

Since the 1980s, it has been argued that mineral producing countries, and developing countries endowed with minerals in particular, may be able to industrialise and diversify¹ their economies further by processing minerals into final products locally (United Nations, 1984). Indeed, mineral producing countries have been implementing policies that aim to encourage or even enforce the downstream processing of minerals (Humphreys, 2013; Zhang et al., 2015; Morris et al., 2012b). Some of these policies have been quite radical. For example, the Government of Botswana has required De Beers to cut and polish its diamonds locally (Morris et al., 2012a). Similarly, Indonesia banned the

export of unprocessed minerals (Humphreys, 2013; Beckmann, 2013) and Zimbabwe banned the export of unrefined gold (Eunomix, 2015).

While it is unlikely that such policies are implemented during a resources slump, many countries are considering pursuing this course of action during or even before the next resource boom. For example, South Africa's Department of Mineral Resources has published a "Beneficiation Strategy" (Department of Mineral Resources, 2011) that calls for local mineral processors to be granted preferential access to raw mineral products through advantageous or "developmental" prices for these local companies, placing levies or taxes on the export of unprocessed items such as diamonds and iron ore, and imposing conditions on the use of infrastructure to force the local processing of extracted minerals. Similar events have unfolded in the Philippines, where, toward the end of the last resource boom, the Government was also considering following the lead of Indonesia and issuing a ban on the export of raw commodities (Beckmann, 2013). Pressure is being applied by regional strategies such as the Africa Mining Vision (AMV), which calls for the local processing of minerals to support industrialisation and economic growth (African Union, 2009).

Some of these policies, notably, in the case of diamonds in Botswana, have been regarded as at least partially successful (Morris, 2012b). However, it has also been recognised that where

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¹ Note that another way to industrialise their economies would be an even 'wider' diversification, i.e. diversifying into completely different industries. Although this is a very valid way to reduce vulnerability and increase growth, in this paper we focus on the possible (further) development of the already existing (extractive) industries, due to the apparent policy interest in and lack of policy guidance for this approach.

these policies place pressure or bring about uncertainty regarding the return on investment, they may lead to reductions in foreign direct investment in the mining industries (Humphreys, 2013). There is therefore a need to carefully consider the possible impacts that any such policy might have and how countries may optimise the impact of their policies. Morris et al. (2012b) studied location policies in sub-Saharan Africa, determining that while many countries may have a general vision for ensuring the maximum benefit from their resources, some fail to articulate and implement it in a meaningful way. The same study also argued that countries have made sub-optimal decisions by not considering which downstream industries can be sustained in the medium to long term, which has often led to the support of unviable industries and at the same time, neglect of viable industries.

With this in mind, this viewpoint first explores the current research that investigates local downstream mineral processing and why it has not supported the prevention of such sub-optimal policy setting. The review identifies a significant gap in terms of understanding the economic location determinants of downstream mineral processing and, therefore, the appropriate/optimal intervention of mineral producing countries in the mineral value chain. The paper then proceeds to formulate a research agenda for addressing this gap.

2. Literature review

Several studies have investigated downstream mineral processing in various countries, in particular, those in the developing world. These studies have been primarily carried out in the context of linkage theory, pioneered by Hirschman (1981) and extended by authors such as Morris et al. (2012a). Linkage theory investigates the various mechanisms that can help to ensure that a mine or other extractive operations do not become an 'enclave' which fail to contribute to the local economy. Morris et al. (2012b) defines four main categories of linkages: 1) fiscal, which refer to the tax revenue collected by the municipal or national Government; 2) consumption, which refer to the demand created for various consumables in the mining region by the wages paid to mine employees; 3) production, which can include either upstream/backward production linkages or downstream/forward production linkages; and 4) horizontal/side-stream linkages, which refer to spill over effects to other industries through the creation of public infrastructure, knowledge transfer, and demand pooling effects. Within production linkages, upstream/backward linkages refer to the local production of inputs required in mining operations such as explosives, capital equipment and protective equipment. Downstream/forward production linkages refer to the further processing of products from mining operations such as the cutting and polishing of diamonds, the type of downstream mineral processing which this article focuses on. The concept of linkages and related work has become the backbone for significant research which investigates the impact, and in particular the benefits and missed opportunities, of the mining industry (Morris et al., 2012a; Bloch and Owusu, 2012; Fessehaie 2012; Adewuyi and Oyejide, 2012; Teke, 2012).

The downstream processing of minerals and the policy issues related to it have also been primarily addressed from a linkage perspective. For example, Bocoum and Labys (1993), Lei et al. (2013) and Ivanova (2014) all take a linkage perspective. The authors use an input-output methodology based on the work of Leontief (1936, 1956) and apply it to the case(s) of copper in Zambia and phosphates in Morocco; various mining industries in China; and coal mining in Australia, respectively. This approach is useful for establishing what the current impact of an industry is (i.e., which linkages currently exist) but at the same time, fails to suggest which industries can and should be promoted. The main

drawback of the linkage theory approach as it is used in the downstream processing literature is that it is not explanatory in nature, but rather primarily descriptive. Furthermore, by considering downstream linkages from the perspective of mining as the focal point, the scope of downstream linkages considered is usually restricted to only one or two downstream processing steps, instead of the entire downstream value chain to final products. The dominance of the linkage theory approach in the input-output form in downstream mineral processing studies has also meant that studies investigating downstream mineral processing questions often address more than one type of linkage. This is because the analytical methods such as the Leontief matrix invariably lead to the analysis of various types of linkages. This limits the depth of research that studies attain regarding downstream linkages in particular.

More recently, authors have noted some of the limitations of the linkage theory approach and aimed to address this by extending the traditional linkage theory analysis of mining activities by adding a global value chain (GVC) and global production network (GPN) analysis approach as pioneered by Gereffi and Korzeniewicz (1994), Gereffi et al. (2005) and Henderson et al. (2002). For example, Bridge (2008) highlighted some of the limits of the linkage approach and referred to the 'stalled policy debate regarding the linkages between resource extraction and socio-economic development'. He suggested that a GPN approach could improve our understanding of linkages in the extractive industries by emphasizing the firm-state relations and their impact on development opportunities. Similarly, Morris et al. (2012b), in what is likely to be the most in-depth recent mineral study that addresses downstream linkages, combine the GVC and linkage theory perspectives in addressing the potential developmental role of the extractive industries.

However, GVC analysis is also an inherently descriptive construct, with aspects such as rents and barriers to entry, "governance", and the identification of different "types" of value chains being introduced to provide some analytical structure to the framework (Kaplinsky and Morris, 2001). The analytical GVC and GPN approaches generally employ one or more of the descriptive maps presented in Gereffi and Fernandez-Stark (2011). These are then analysed to identify what type of power relations exist in the value chain, where rents are captured and how income is distributed between the different actors. This might be useful in understanding where in the value chain firms may have an upper hand because of limited competition and which steps in the value chain have the most potential for value added (Kaplinsky and Morris, 2001). However, it provides little insight into the fundamental economic factors that underlie the location of economic activities and the viability of undertaking such activities within a country. Thus, the GVC and GPN extension does little to address the main criticism of the linkage theory approach. Though it may increase the scope of the analysis beyond one or two steps of the value chain, the extension remains a primarily descriptive methodology. Furthermore, apart from including the role of multinational firms and their interaction with local Governments in determining where mineral processing takes place, the GVC extension of linkage theory does little to connect with established economic location theory. Indeed, the methodology lacks dynamism and does not allow an understanding of and how active policies could change location outcomes.

Nonetheless, linkage theory and the GVC and GPN approaches describe the location of mineral extraction and processing and as such are useful in providing an initial insight into these location outcomes. However, better – more than merely descriptive – understanding of the exact location determinants is needed in order to provide solid policy recommendations as well as to gain a fuller picture of the welfare implications of policy interventions.

Table 1
The economic location determinants of firms.

First nature (Neo-classical 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 costs that determine the distance to suppliers/final market
(2) Geography of the country (e.g. landlocked or not)	

Source: De Bruyne (2006).

Indeed, there still exists a theoretical gap when it comes to explaining the apparent lack of downstream linkages in many developing mineral producing countries. As Morris et al. (2011) explain 'there is an almost complete absence of data and supporting analyses on the nature and determinants of existing patterns of linkages which can be used to inform actions for the future'.

Various other studies have already identified factors which likely affect the location of the downstream processing of minerals that go beyond the linkage theory and are therefore more predictive and explanatory in nature. One of these studies is, the United Nations (UN) 'Mineral Processing in Developing Countries' study published in 1984 (UN, 1984). Similar to the premise of this paper, the study examined 'the factors which affect the location of mineral processing in developing countries' and identified two broad categories. First, 'technical and economic elements affecting the viability of a project' e.g. capital, skilled labour, raw materials, complementary inputs, energy, economies of scale, technological change, growth in demand, proximity to export markets and transport costs. And second, 'structural elements' (e.g. sources of finance and technology, trade and investment and taxation policies). However, similar to other studies, the UN study stopped short of determining the relative importance of the various factors that influence the downstream processing of minerals or connecting them to established economic location theory. Rather, each of the factors were considered qualitatively and in an isolated manner. In contrast, several studies do measure the importance of different location determinants – as well as their interaction – for economic activity in general (De Bruyne, 2010; ; Mion, 2004; Hanson, 2005 De Bruyne, 2010; Mion, 2004; Hanson, 2005). However, this literature has not yet been integrated with the mineral resource literature and policy debates. Crucial to the research agenda is therefore a better understanding of the theoretically-underpinned location determinants to evaluate the effectiveness of the policy instruments aimed at influencing mineral processing location. The various economic factors that may influence the location of firms in general – and therefore also of downstream mineral processing in particular – can be loosely divided into two main categories, as shown in Table 1 (De Bruyne, 2006). Both first and second nature location determinants are derived from well-known trade and economic geography models (see Fujita et al., 1999).

The first nature theories are exogenous – implying that they determine the location of a firm directly. Indeed, Neo-Classical Trade Theories (NCT) propose that firms might want to settle in countries with raw materials or a high-skilled labour force. If it is important for them to ship their final or intermediate products at low cost, they may want to locate in a country with a major harbour or (hub) airport. Although NCT theories were originally developed to explain trade patterns between countries, they automatically affect location outcomes.

The second nature theories are endogenous – implying that they induce a snowball effect. In the New Economic Geography

Theories (NEG) the location of economic activity is determined by 'centripetal' and 'centrifugal' forces. Centripetal forces pull firms towards the centre of economic activity. Such forces occur in the presence of e.g. suitable factors of production, easy access to markets, and benefits from increasing returns to scale. Conversely, centrifugal forces push firms away from the centre of economic activity. Examples are negative externalities such as congestion. The NEG theories analyse when firms prefer to locate in the centre of economic activity and when they prefer to move to the periphery, depending on the strength of these forces. The snowball effect (caused by centripetal forces) can best be explained using an example. Final producers want to locate close to their intermediate suppliers, with a view toward providing an important market for these intermediate suppliers and therefore attracting even more intermediate suppliers to the country (or to the centre in this case). These new intermediate suppliers in turn will attract new final producers. In the end, a cluster of final producers and intermediate suppliers will emerge. It is important to understand that the snowball effect and centripetal forces may be counterbalanced by centrifugal forces. Indeed, if for instance due to congestion, production becomes too expensive, firms may prefer to leave the centre of economic activity. The cluster will therefore remain as long as the centripetal forces (cluster benefits) outweigh the centrifugal forces (congestion).

Given the importance of location determinants as captured in the first and second nature theories, Governments and policy-makers can intervene to increase or counteract the impact of these determinants. The degree to which they can make a difference depends on the key factors that are relevant for a specific region and industry as well as the resources and power at their disposal. Baldwin et al. (2005) identify three categories of interventions that policymakers may pursue to influence location outcomes.² These are shown in Table 2.

It is therefore argued here, that an improved understanding of the key location determinants at play is crucial to determine which policy instruments within these three categories would be suitable to pursue in a given context. It is obvious that all three policy interventions have a direct (first-nature) impact on location. As a practical example of policy-related location determinants one and two, it may be argued that by cutting taxes on labour or investing in education, Governments may attract firms that require semi- or high-skilled labour. Linking back to downstream mineral processing, a Government might, for instance, opt to invest in education such that it becomes more lucrative for a downstream mineral processing firm requiring skilled labour to locate in the country. Take the case of manganese production. As far as the extraction itself is concerned, low-skilled labour is a crucial input factor. In further stages downstream in the value chain (e.g. alloy, electrolytic manganese dioxide and electrolytic manganese metal

² Baldwin et al. (2005) focus on the impact of public policy under second nature theories (snowball effects). It is however obvious that these policies may also have an initial impact under first nature theories.

Table 2

Categories of location interventions available to policy makers.

- | |
|--|
| (1) Government intervention in the form of subsidies or taxes |
| (2) Government investments in infrastructure, technology, education, . . . |
| (3) Trade policy |

Source: Baldwin et al. (2005).

production), semi-skilled labour is required. If the Government therefore opts to educate its local labour force, it might be able to attract downstream mineral processing. By giving incentives to export, Governments might also attract exporting firms within their borders and/or stimulate domestic firms to export more in a particular stage of the value chain. This constitutes an example of a policy-related location determinant, as shown in Table 2. One concrete example is the Chinese industrial policy on the rare earth element (REE) industry, implemented in 2010, which imposed export duties and export quotas on REE exports. However, the EU, US and Japan challenged this policy at the WTO (World Trade Organisation) and the WTO ruled against China in 2014.³

Baldwin et al. (2005) illustrate that under second nature location theories, Government policy may even have a larger impact on location. Indeed, given the snowball effect, a small Government intervention may have a large final impact. Linking back to downstream mineral processing, a Government might temporarily subsidise part of the downstream mineral processing industry and thus start a snowball effect attracting more and more final and intermediate producers. Indeed, if a country manages to attract a processing stage in the global value chain, it might attract more processing stages later on and even other related and unrelated industries.

From both policy examples, it is obvious that developing countries will unfortunately not always be able to pursue their preferred policy. First of all, they might face financial constraints to, for example, increase subsidies or decrease taxes. Second, as a member of the WTO, they have to take WTO rules into account when they develop their trade policies. Nonetheless, despite these constraints, the analysis of optimal policies to attract downstream mineral processing remains highly important for developing countries. Relating to the financial constraint, defining optimal policies is crucial to: (i) understand how developing countries could improve their situation in the most cost-effective manner that could lead to a sustainable competitive advantage; and (ii) understand how international organizations might best help the development of these countries cost-effectively. Linking to the limitations as far as trade policy is concerned, the WTO already allows many waivers for developing countries. Indeed, developing countries are given longer timetables for implementing many important provisions and commitments precisely in order to allow them to protect nascent industries should they choose. However, in order to grant such exceptions, the WTO requires convincing arguments for which industries these exceptions are 'justified'. A thorough understanding of the key location determinants is therefore indispensable.

The ultimate question remains whether countries or regions have already been successful in implementing policies addressing location issues in general, aside from just the case of mineral resources. Similar to downstream mineral processing policy, Anderson (2012) defines regional policy in general as public sector interventions designed to prevent peripheral, less developed regions that are often specialized in the production of resource-based commodities from falling behind. Examples of strategies to obtain these objectives include investment in human

capital and infrastructure – policies that are based on economic location determinants, as discussed in Table 1. Such regional policy programmes have been adopted in a variety of countries over the past few years. For example, programmes have been implemented to assist the northeast region of Brazil and several (lagging) European regions. The main goal of the European Regional Policy is to eliminate regional economic disparities. Empirical evidence about whether this goal has been achieved is, however, mixed at best. Moreover, these policies were not aimed at particular sectors. Indeed, apart from very specific cases discussed in the introduction,⁴ the identification and analysis of first or second nature policy measures within the context of downstream mineral processing has been lacking. A better understanding of why firms set up their activities in a particular location – and the linkages this implies – makes for a more solid analysis of policy measures than the existing approaches discussed.

3. Setting the research agenda

Given the context provided in the previous section, it is argued that to arrive at a sound policy framework regarding the governance of downstream mineral processing, three interrelated areas of research need to be developed. First, it is crucial to map and understand the current distribution of mineral processing activities globally. Second, there is a need to test theories explaining the global distribution of mineral processing activities. Third, the various policy options that are available to mineral producing countries need to be identified and their merits and demerits evaluated in different circumstances.

To expand, the global distribution of extracting activities – as well as the downstream mineral processing – has to be mapped based on the available trade and production data. The key at this stage is to select the appropriate minerals for investigation in order to arrive at generalizable results for key mineral types. In other words, the case selection will have to be such that the minerals chosen are representative of economically important groups of minerals. For each extracting activity, as well as for each stage of downstream mineral processing, the production share needs to be calculated in every country so as to establish which production stages are currently located where. This stage will provide the empirical backdrop for the following two research areas. In a second stage, the economic location determinants need to be defined and the theories that explain the global distribution of mineral processing activities need to be tested. In order to define the economic location determinants, information from input/output tables as well as information from industry surveys should be combined. Once the possible location determinants are known, one can turn to testing the theories. In particular, the current linkage theory and GVC and GPN approaches, as applied by both Morris et al. (2012b) and Bridge (2008) have to be enriched by applying theoretically underpinned location theories. Specifically, (i) NCT theories are needed to understand the impact of various national factor endowments on the location of mineral processing activities, and will have to be combined with (ii) a NEG approach to account for the snowball effect observed in various global value chains. As examples, see De Bruyne (2010) for an ANOVA analysis to determine the relative importance of the NCT/NEG theories, or Sukkoo (1999) and Amiti (1999) for an analysis to determine the importance of NCT theories. It is obvious that the economic location determinants will vary among countries, industries, and different stages in the value chain within industries.

Once the economic location determinants are fully understood and tested for, one can move to the policy part of the research

³ Note that Zhang et al. (2015) show that although the duties and quotas had to be removed, China substantially increased the market power of its REE industry.

⁴ Diamonds in Botswana, Gold in Zimbabwe, REE in China.

agenda. In a third stage, the policy options available to mineral producing countries in order to attract downstream mineral producing activities have to be identified based on the primary economic location determinants. Special attention also needs to be paid to the feasibility of these policies – as underlined in the previous section. This stage also has to include an investigation and evaluation of policies that have already been implemented by different countries with extractive industries.

4. Conclusion

The recent increase in the implementation of various policies that aim to encourage or even force the downstream processing of minerals has highlighted the need for research to better inform policy makers. Specifically, it is crucial to be able to determine whether and how mineral producing countries can and should intervene in the processing location of minerals. This paper has highlighted the need to move beyond the linkage theory and the GVC and GPN approaches to incorporate trade and economic geography theories in order to gain a complete picture of the economic location determinants. A profound understanding of the location determinants is imperative to determine the appropriate policy measures to influence these location outcomes. Finally, this has to be complemented by an identification and evaluation of the policy options available/attainable to mineral producing countries in order to attract – or maintain – the downstream processing of minerals. It is contended that this approach will lead to the development of improved policy recommendations for mineral dependent developing countries seeking to expand the downstream processing of minerals and thus help to increase the value that they attain from their mineral resources.

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6.3 Conclusion: Chapter 6

This chapter considers why there is a need for understanding location determinants in order to better inform downstream mineral processing related policy. In particular, it critiques the existing literature that deals with downstream mineral processing policy and highlights the need for further work in evaluating the key factors that drive the location of mineral processing activities. It thereby lays the foundation for the following chapter (Chapter 7) that investigates the key factors that may affect the location of economic activities in general and how these factors may be combined to construct a framework that may be used to systematically evaluate the factors affecting the location of a specific activity.

Chapter 7

Evaluating the factors driving the location of economic activities

This chapter is the second of two chapters that aim to address the third objective of this research, namely to “develop a new analytical framework that enables the appraisal of the factors driving the location of particular downstream mineral processing activities to understand how such activities could be targeted (and thus attain a first approximation of the cost and feasibility of doing so)”. This chapter investigates the key factors that may affect the location of economic activities in general and how these factors may be combined to construct a framework that may be used to systematically evaluate the factors affecting the location of a specific activity. This chapter consists of three sections. The first (Section 7.1) situates the chapter within the narrative of the dissertation (as summarised in Figure 7.1). The second section (Section 7.2) contains the article which comprises the primary part of this chapter. Finally, Section 7.3 concludes the chapter by summarising its contribution to the dissertation.

7.1 Introduction: Chapter 7

The previous chapter (Chapter 6) argued that there is a need for research to address the determinants that drive the location of mineral processing activities. This could enable policy-makers to appreciate what, if anything, could be done to support the establishment of a specific mineral processing industry in a particular location. This also provides policy-makers with an understanding of the nature and expected cost of intervention that would be required in order to enable the emergence of a particular industry. Hence, this chapter reviews the factors that influence the location of economic activities. These factors are then consolidated into a conceptual framework and supporting analytical process to guide the systematic evaluation of location determinants for a particular activity. This thus directly addresses the third and final objective of

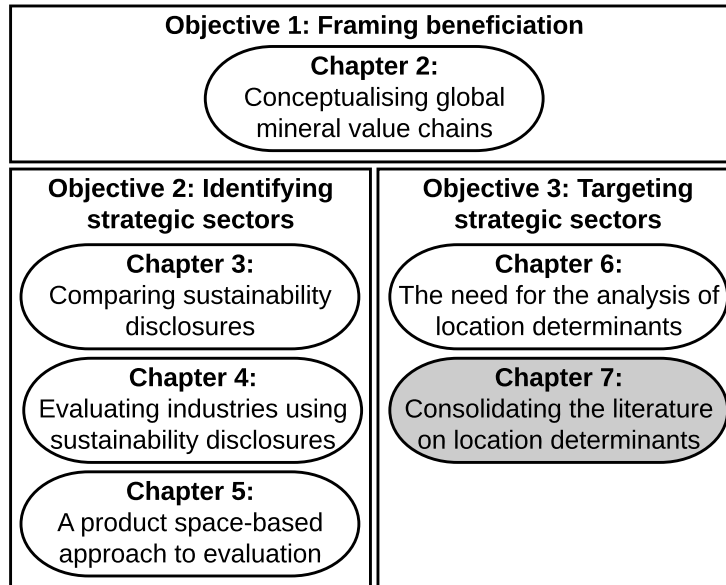


Figure 7.1: Position of Chapter 7 in dissertation.

this dissertation, namely, to “develop a new analytical framework that enables the appraisal of the factors driving the location of particular downstream mineral processing activities to understand how such activities could be targeted (and thus attain a first approximation of the cost and feasibility of doing so)”.

7.2 Article: “A review of factors affecting the location of economic activities: a multi-disciplinary approach”

The article presented in this section is an author original manuscript (AOM) which had not been yet been accepted for publication at the time of writing (30 May 2019). The AOM version contained here does not include any improvements based on the peer-review process.

Factors affecting the location of economic activities: a multi-disciplinary review and conceptual framework

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Abstract:

Many fields of literature address the location of economic activity. However, a holistic framework that integrates and enables a systematic evaluation of the factors affecting the location of economic activities has thus far been lacking. By means of a structured literature review, this research summarizes the key developments in the main fields of literature that address this issue. Based on this review, a novel conceptual framework is proposed. The proposed framework is **location centric** i.e. it evaluates the performance of a location in terms of supporting a specific activity aimed at a particular market. The framework aims to assist both firms and policy-makers in evaluating the key location determinants that drive the location of particular activities. This has the potential to support improved location decisions by firms and industrial policy by governments. We also highlight the need for future research to further improve our understanding of the factors driving the location of economic activities.

Keywords: Location decision determinants; Structured literature review; FDI; location decisions; location policy.

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1 Introduction

The factors that influence where firms initiate and locate their activities is of interest to a variety of stakeholders. Consequently, these factors are studied in a number of academic fields. This ranges from studies that aim to evaluate patterns of economic activity with the aim to, *inter alia*, improve urban and regional planning (Kanai and Schindler, 2018); studies that aim to understand how firms can best locate their activities to gain a competitive advantage (Alcácer and Chung, 2014); and studies that enable governments to identify location-based factors that may be constraining economic growth (Redding and Schott, 2003). Despite the rich variety of literature addressing location determinants, there appears to be a limited number of studies that even attempt to provide a more holistic conceptualisation of them³ (Blonigen, 2005). Consequently, there exists a proliferation of theories and approaches that focus on different levels of analysis, resulting in much conceptual confusion in terms of what these factors are and how they interact (Pellenbarg et al., 2002). Such studies are also performed in a diversity of fields and thus may be isolated from one another to various extents due to different academic traditions (e.g. Alcácer & Chung 2014; Bhutta et al. 2003; Ellison & Glaeser 1997).

Furthermore, Bam & De Bruyne (2017) argue that there exists a need for tools that (i) identify the key location decision determinants at play for a particular activity; and (ii) given the location decision determinants, determine the fit of that activity within a particular region given the region's specific properties. The need for such frameworks has grown due to the increasingly global nature of supply chains and the associated increasing importance of location determinants (Baldwin, 2013). Furthermore, the growing importance of wider considerations such as social and environmental impact have also increased the number of aspects that such frameworks must address (Chen et al., 2014).

It seems clear that there is a need to better integrate the developments in each of the disparate fields addressing location determinants in order to propose a state-of-the-art holistic conceptualisation and systematic evaluation process of the location determinants influencing economic activities. This could not only support firms and policy practitioners in decision making, but also provide a frame of reference for future research. Firms themselves are naturally a first important stakeholder of such a framework as it could provide them with insight into the location-related factors that may influence their performance. Such a framework could thus be valuable in their location-related decision-making processes. Secondly, if governments want to attract a particular type of firm, they also require a full understanding of all location determinants that may affect firm location decisions. This is particularly relevant within the framework of development policy – and beneficiation policy in particular (Bam and De Bruyne, 2018). For researchers, such a framework could guide future research in terms of highlighting gaps in knowledge and providing a harmonised frame of reference to improve interdisciplinary harmonisation.

³ Notable exceptions include works such as Chen et al. (2014) and Dunning (1998).

Towards such a framework, we review the rich literature on the location of economic activities in order to *identify the key location determinants that affect the location decisions of economic activities*. In particular, we seek to identify patterns, overlaps and complementarities in terms of the factors considered. Our goal is to consolidate these in a conceptual framework. We embed this framework in a phased assessment process that enables the systematic consideration of the key location determinants identified in the different research fields.

The remainder of this paper is structured as follows. Section 2 provides an initial overview of the main fields addressing location determinants. The methodology followed to review these fields in a structured manner is discussed in Section 3. Section 4 tackles the results obtained from the review. Section 5 presents a novel conceptual framework of the key factors that affect the location of economic activities, along with a supporting 4-phase analytical process. Finally, Section 6 summarises the paper and concludes with a discussion of the implications of the research. Appendix A provides more detail on the review results, while Appendix B contains the detailed element of the framework (the summary of which is contained in Section 5). Finally, the supplementary material to this article (S1), provides further background information on the review methodology and methodologies employed in the reviewed articles.

2 Literature fields considered

Before the structured review was performed, an extensive exploratory literature review was undertaken to identify the main fields that have contributed towards the rich variety of literature addressing location determinants. This section provides an overview of the six fields identified during the exploratory review.

The field of **general economics** has systematically addressed different location determinants over time. Some of the early dominant frameworks related to the location of economic activities include the law of comparative advantage put forward by Ricardo (1817) and the related factor-proportions theory (Ohlin, 1933). A more recent wave of interest in factors affecting the location of economic activities within mainstream economics was driven by works such as Krugman (1991a) and Venables (1996), which established the so-called new economic geography (NEG) strand of research in economics (Krugman, 2011, 2009). The NEG models provide an endogenous perspective and show that an initial location determinant can attract a firm but by doing so can also reinforce the strength of the location determinant itself and therefore attract more firms in the future until this effect is counteracted by emerging congestion effects. This is referred to as the snowball-effect (De Bruyne, 2006).

The **economic geography literature** studies the location and spatial organization of economic activities across the world. It represents a traditional subfield of the discipline of geography. However, as geography has been increasing in importance in general economics, many economists have also contributed to the field in ways more typical of the discipline of economics. Some of the first roots of the field of economic geography can be traced to classical location theory (Moses, 1958; Weber, 1909), studies focussed on the market area and emerging location patterns if decision-makers seek to make optimal location decisions (Hotelling, 1929; Palander, 1935), and central place theory (CPT) (Christaller, 1933; Losch, 1954). More recent developments in this field include the renewed interest in industrial clusters (Gordon and

McCann, 2000). These build on the work of early industrial geographers such as Marshall (1920) and the related impact of knowledge generation and transfer on the geography of economic activities (Storper, 2009).

The **general management literature**, seeking to support management and policy decisions, has seen a number of attempts to consolidate an understanding of location determinants and how they impact profitability. Arguably, one of the best known frameworks that addresses location in a wider context is the eclectic paradigm put forward by John H. Dunning, focussing on the ownership, locational and internalisation advantages and how they impact the foreign direct investment behaviour of firms (Dunning, 1998, 1988, 1983). Another attempt that supposes a framework of location determinants that has had considerable influence, is the diamond of competitiveness proposed by Porter (1990), which supported a period of renewed interest in activity clusters, including in the economic geography literature (McCann, 2008; Smit, 2010). Another influential model in the management literature has been that proposed by Ferdows (1997), which focussed on the different roles that plants may fulfil in a manufacturing company's strategy and how these roles influence location choice (Cheng et al., 2015).

The **operations and production management literature** has also seen some examples aimed at providing a more holistic consideration of factors influencing the location of economic activities. The subject is often framed in the context of companies seeking to optimise their competitive positions by locating different activities in particular locations. Illustrative studies include the Delphi study undertaken by MacCarthy & Atthirawong (2003) and the thesis by Pongpanich (1999), both of which focus on the factors that influence the international location decisions for manufacturing operations. More recent operations and production management literature has addressed location determinants in the context of the off-shoring and reshoring debate (Gray et al., 2017; Ketokivi et al., 2017). Chen, Olhager and Tang (2014) provide a literature overview of the different location determinants within the operations and production management literature where they allow for the increasing importance of sustainability in location decisions – something that has been largely missing in, for example, the general economics literature.

Another field of analysis implicitly addressing an important range of determinants that influence the location of economic activities can be found in the literature focussing on **innovation**. This includes works focussing on national systems of innovation (Godin, 2009; Lundvall, 2007), regional innovation systems (Cooke et al., 1997), sectoral innovation systems (Breschi and Malerba, 1997; Malerba, 2002), technology innovations systems (Bergek et al., 2008; Hekkert et al., 2007; Wieczorek and Hekkert, 2012) and the literature regarding socio-technical systems (Geels, 2004; Geels et al., 2016).

In the **development literature**, a rising number of articles are tangentially or implicitly addressing the location choices of economic actors. This includes articles building on the global value chain (GVC) framework proposed by Gereffi et al. (2005) and the global production network (GPN) framework proposed by Henderson et al. (2002). Most of these discussions have focussed on power relations between different economic actors in value chains and the

developmental and value capture implications of these relations (Gereffi and Lee, 2012; Ravenhill, 2014).

3 Research methodology

After the identification of the six research fields that address location determinants through the exploratory literature review, a structured review of each of the identified main academic fields was undertaken. This review sought to identify the most influential research that i) addresses the factors that influence the location of economic activities and ii) consolidates these factors into more holistic conceptual frameworks.

Two approaches were followed to identify relevant articles in each of the identified fields. Firstly, a journal-based approach was followed whereby relevant publications in the leading journals in each of the identified fields were identified. Secondly, the Scopus[®] research field functionality was used to identify any highly cited papers that were not included by following the journal-based identification approach. The final sample of articles was then studied, and the findings consolidated and compared for the different fields.

For the journal-based approach, the search was limited to the top five (in terms of impact) relevant journals in each of the six fields. The impact of journals was evaluated by studying their 2017 SCImago[®] Journal & Country Rank (SJR) values as reported on the public SCImago[®] website based on the citation data from Scopus[®] (Scimago Lab, 2018). This metric was chosen – despite some of its known drawbacks (González-Pereira et al., 2010) – as it does not merely rank journals by the number of citations per article, but by the quality of those citations based on a PageRank algorithm (Falagas et al., 2008; Jacsó, 2010). For each field of research, a relevant subject area and subject category(ies) was/were identified on the SCImago[®] website (these are indicated in Table 1). Within these categories, journals were ranked according to their SJR ranking and the top five relevant journals were identified. The relevance of journals was determined by studying the aim descriptions on their home pages. Two of the authors independently reviewed the top-rated journals and selected the top five (in terms of SJR score) journals that were relevant to this study for each field. The two lists were then compared and any discrepancies settled through consensus and discussion with the third author. A summary of the resultant journal choices is presented in Table 1.

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Table 1: Summary of selected journals.

<u>Research field</u>	<u>General economics</u>	<u>Economic geography</u>	<u>General management</u>	<u>Operations and production management</u>	<u>Innovation studies</u>	<u>Development studies</u>
<u>Subject area (SJR)</u>	Economics, Econometrics and Finance	Social Sciences	Business, Management and Accounting	Engineering; Economics, Econometrics and Finance; Business Management and Accounting	Business, Management and Accounting	Social Sciences
<u>Subject category (SJR)</u>	Economics and Econometrics	Geography, Planning and Development	Strategy and Management; Business and International Management	Industrial and Manufacturing Engineering; Economics, Econometrics and Finance (miscellaneous); Business Management and Accounting (miscellaneous)	Management of Technology and Innovation	Development
<u>Journals selected</u>	Quarterly Journal of Economics	Journal of Economic Geography	Academy of Management Annals	Journal of Operations Management	Research Policy	Journal of Development Economics
	Econometrica	Economic Geography	Academy of Management Journal	Journal of Supply Chain Management	Journal of Product Innovation Management	World Bank Research Observer
	Journal of Political Economy	Cambridge Journal of Regions, Economy and Society	Strategic Management Journal	Production and Operations Management	Technovation	Population and Development Review
	American Economic Review	Environment and Planning D: Society and Space	Academy of Management Review	International Journal of Production Economics	Innovation Policy and the Economy	World Development
	Review of Economic Studies	Environment and Planning A	Journal of Management	Journal of Business Logistics	Technological Forecasting and Social Change	International Journal of Urban and Regional Research

Within these journals, the most influential articles that relate to the location decisions of economic activities were sought. The articles were required to provide either: i) a discussion of a factor(s)/empirical study of the factors that affect(s) the location of economic activities; or ii) frameworks that theoretically/conceptually combine the factors that may affect the location of economic activities. To ensure that only articles relating to the location of economic activities were included, an abstract, title and keyword search was performed for each field, limited to the selected journals, for all articles that include the term: *locat** – the asterisk denotes that all alternative endings to the term (such as *location*, *locating* and *locate*) are also included in the search. To ensure that the articles further relate to one of the two location themes described above, matching documents were further required to also include: i) the term *Framework** or *Model**; or ii) *Factor** or *Element** or *Driver** or *Variable** or *Determinant**. The resulting number of documents for each field that meet these search term requirements is indicated in Table 2.

Within the sample for each field, the 50 most cited articles were reviewed in order to determine their relevance to one of the two aims of the review. The first filtering was done on the title to exclude any articles that clearly did not match the review aims. This was followed by a further filtering that included at least reviewing each article's abstracts and, in most cases, the rest of the paper to determine if it contributes to the stated aims of the review. The number of articles identified as relevant and hence included in the full review after this manual filtering of the top 50 most cited articles in each field are also indicated in Table 2.

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Table 2: Number of documents matching search criteria in the chosen journals.

	General economics	Economic geography	General management
# of documents included in full review	9	15	17
# of document meeting search term requirements	101	396	71
Total # of documents in journals listed on Scopus® on search date⁴	15 155	6 447	7 390
	Operations and production management⁵	Innovation studies	Development studies
# of documents included in full review	12	26	8
# of document meeting search requirements	344	176	153
Total # of documents in journals listed on Scopus® on search date	9 728	11 095	12 259

To ensure that no crucial articles were omitted due to the choice of journals, the Scopus® subject area functionality was used to identify any highly cited papers not included in the journal-based approach that meet our search criteria. The top 200 documents (in terms of citations) meeting the search criteria in any of the following Scopus® subject areas were reviewed and added to each of the six research fields as appropriate: i) Social Sciences; ii) Business, Management and Accounting; and iii) Economics, Econometrics and Finance⁶. These papers were then filtered in a similar manner to the filtering of the papers identified through the journal search. The contribution of the additional search to the journal-based sample is shown in Table 3. Table S1.A in Supplementary material S1 summarises the date and citation range of the final sample for each research domain.

⁴ Searches were performed between the 31st of July 2018 and the 5th of September 2018.

⁵ One article in the innovation management journal sample (Bhatnagar and Sohal, 2005) was found to relate to location decisions in the context of supply chains. It was therefore reclassified in the operations and production management sample.

⁶ Search performed on the 24th of September 2018

Table 3: Contribution of additional search to final literature sample.

	General economics	Economic geography	General management	Operations and production management	Innovation studies	Development studies
# of new documents added to final sample	5	4	1	1	0	1
# of documents already in journal based review	6	2	5	0	2	0

4 Review results

The results from the detailed review of the final document sample in each academic field is discussed in this section according to the i) the general themes covered; ii) the unit of analysis employed; iii) the key market related factors considered; iv) the location related factors considered; and v) interactions and dynamics considered.

4.1 General themes

The general themes addressed in each field are identified in Table 4 along with their references. Apart from these themes, some observations can be made regarding peculiarities in the samples. In the **general economics** field, the studies generally focussed on a limited number of determinants or used higher-level determinants that would be composed of a variety of sub-determinants in studies in other fields. In the **economic geography** sample, many articles appear to focus on concepts related to the cluster theory. The **general management literature** can be distinguished from the general economics and economic geography literature based on its particular focus on the firm and its strategy. Furthermore, many articles in the management literature sample explicitly align with or critique particular theoretical schools of thought. Some of the most often mentioned in the sample include internalisation/transaction cost theory, the OLI framework/eclectic paradigm, the resource-based view/theory, capability theory, neo-institutional theory, oligopolistic interaction, agglomeration theory, international product life cycle theory and stage theory of internationalisation. The **operations and production management literature** sample generally focusses on providing firms with guidance to improve their decision-making. One article in the sample explicitly refers to sustainability considerations as captured in the concept of the triple bottom line and how all three of these considerations (economic, social and environmental) might influence locational decisions. This provides a perspective that is not thoroughly considered in any of the other literature samples. A number of articles in the **innovation management literature** sample are similar to the management literature in the sense that there is a particular focus on firms and multinational firms in particular. However, the focus is specifically on the R&D functions of the firm. The articles in the **development studies** sample tend to draw predominantly from either the general economics or economic geography methodologies. **Supplementary material S1** provides an overview of the methodologies utilised in each paper and provides a summary of these methodologies in Table S1.B.

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Table 4: General themes per field.

	Theme	Reference
General econ.	Economic agglomeration determinants	Ellison and Glaeser, 1997; Head et al., 1995; Krugman, 1991a, 1991b; Lael Brainard, 1997; Venables, 1996.
	Factor productivity determinants	Bloom et al., 2012; Hall and Jones, 1999.
	FDI determinants	Blonigen, 2005; Cheng and Kwan, 2000; Coughlin et al., 1991.
	International trade determinants	Antràs and Helpman, 2004; Grossman and Helpman, 2005.
	Development determinants	Gennaioli et al., 2013.
Economic geography	Conceptualisation and dynamics of clusters	Bresnahan et al., 2001; Gordon and McCann, 2000; Henry and Pinch, 2001; Malmberg and Maskell, 2002; Martin and Sunley, 2003; Pinch et al., 2003; Sturgeon, 2003; Suire and Vicente, 2009; Wei et al., 2007.
	Conceptualisation of localisation	Torre and Rallet, 2005.
	Dynamics of knowledge generation and protection	Maskell and Malmberg, 1999.
	Dynamics of knowledge spillovers	Mariotti et al., 2010.
	Innovation determinants	Fitjar and Rodríguez-Pose, 2011.
	Firm headquarter location decisions	Bel and Fageda, 2008.
	Location behaviour of entrepreneurial firms	Stam, 2007.
	Empirical location patterns in industry	Mair et al., 1988.
	Critique of existing research and research agenda	Storper, 2009.
	Determinants of growth of cities in developing countries	Venables, 2005.
Similarities between "new economic geography" models	Robert-Nicoud, 2005.	
General management	Behaviour, choices and strategy of multinational firms	Barkema et al., 1996; Belderbos et al., 2011; Belderbos and Sleuwaegen, 2005; Cantwell and Mudambi, 2005; Dunning, 1998; Feinberg and Gupta, 2004; Hennart and Park, 1994; Madhok, 1997; Medcof, 2001; Rugman and Verbeke, 2001; Song, 2002.
	Conceptualisation and dynamics of clusters	Bell, 2005; McEvily and Zaheer, 1999.
	Agglomeration decisions	Alcácer and Chung, 2014; Canina et al., 2005.
	Conceptualisation of firm knowledge	Decarolis and Deeds, 1999.
	Optimising facility location	Haug, 1985.
	Innovation strategies of firms	Mueller et al., 2013.
Ops. & prod. man.	Performance implications of firms' locational decisions	Bogataj and Bogataj, 2007; Christopher and Towill, 2000; Gray et al., 2011; Karpak and Topcu, 2010.
	Evaluating how more optimal decisions regarding facility location may be approached	Baron et al., 2011; Bhatnagar and Sohal, 2005; Chen et al., 2014; Ellram et al., 2013; Vila et al., 2006.
	Methods for activity allocation to facilities in different locations	Badri, 1999; Bhutta et al., 2003; Gebennini et al., 2009; Thanh et al., 2008.
Innovation management	R&D and innovation activities of firms	Christensen, 1995; Gerybadze and Reger, 1999; Håkanson and Nobel, 1993; Kenney and Florida, 1994; Kessler and Chakrabarti, 1999; Love and Roper, 2001; Meyer-Krahmer and Reger, 1999; Miller, 1994; Patel and Vega, 1999; Petruzzelli, 2011; von Zedtwitz and Gassmann, 2002.
	Determinants of the emergence and performance of new-technology based firms (NTBFs)	Colombo and Delmastro, 2002; Löfsten and Lindelöf, 2003, 2002.
	International trends related to global R&D	Cantwell and Vertova, 2004; Guellec and Van Pottelsberghe De La Potterie, 2001; Howells, 1990.
	Innovation related dynamics in clusters/regions	Audretsch et al., 2005; Audretsch and Lehmann, 2005; Baptista and Swann, 1998; Delgado et al., 2014; Gittelman, 2006; Iammarino and McCann, 2006; Silvestre and Dalcol, 2009; Stuart and Sorenson, 2003; Tappeiner et al., 2008.
Development studies	Determinants of FDI location	Amiti and Smarzynska Javorcik, 2008; Dean et al., 2009; Gastanaga et al., 1998; Wang, 2013.
	Determinants of R&D location	Kumar, 1996.
	Location related determinants that affect economic development	Démurger, 2001; Redding and Schott, 2003.
	Patterns of activity linkages in the automotive industry and how they affect the developmental outcomes in the location where these activities take place	Frigant and Lung, 2002; Larsson, 2002.

4.2 Unit of analysis

The units of analysis vary throughout the studies. The general economics sample often focusses on the country or state level. The economic geography literature more often focusses on the regional level, while the general management, operations and production management, innovation management and even development studies literature sample all include a number of studies using the firm as the key unit of analysis. These different units of analysis imply different abilities to generalise, and also the attainment of different insights. The general management and innovation management samples also highlight the value of using a unit of analysis even more granular than the firms itself. In particular, the general management literature elaborates on the distinction between functions and the roles of different subsidiary facilities in different locations over time. Specifically, certain articles explicitly distinguish between the location of manufacturing (Dunning, 1998; Medcof, 2001; Rugman and Verbeke, 2001), research and development (Cantwell and Mudambi, 2005; Feinberg and Gupta, 2004; Medcof, 2001; Rugman and Verbeke, 2001) and marketing (Dunning, 1998; Medcof, 2001) functions. In the context of the multinational firm, different types of subsidiaries are identified with various roles and capabilities (Cantwell and Mudambi, 2005; Dunning, 1998; Medcof, 2001) and hence power in the firm (Medcof, 2001). However, Rugman and Verbeke (2001) warn of overly relying on classifying the roles of subsidiaries, as one subsidiary may have various roles concurrently which are dynamic over time. The innovation management sample underscores the importance of untangling the different activities that make up R&D and the decomposability of the underlying activities. R&D might, for example, be decomposed into i) research and ii) development, respectively (von Zedtwitz and Gassmann, 2002) or i) basic research, ii) applied research and iii) development (Howells, 1990).

4.3 Market related considerations

The most recurring theme identified in the **general economics** literature was related to the location (Fujita and Thisse, 1986; Krugman, 1991a, 1991b; Lael Brainard, 1997) and size of demand/regional markets (Blonigen, 2005; Cheng and Kwan, 2000) or so called “downstream (output) linkages” (Ellison and Glaeser, 1997; Evans and Harrigan, 2005; Grossman and Helpman, 2005). This was also echoed in the **economic geography** (Bel and Fageda, 2008; Bresnahan et al., 2001; Robert-Nicoud, 2005), **general management** (Belderbos and Sleuwaegen, 2005; Cantwell and Mudambi, 2005; Dunning, 1998; Haug, 1985; Hennart and Park, 1994; Mueller et al., 2013), **operations and production management** (Badri, 1999; Bhatnagar and Sohal, 2005; Bhutta et al., 2003; Chen et al., 2014; Ellram et al., 2013; Gebennini et al., 2009; Vila et al., 2006), **innovation management** (Håkanson and Nobel, 1993; Howells, 1990; Miller, 1994; Patel and Vega, 1999; von Zedtwitz and Gassmann, 2002) and **development studies** (Dean et al., 2009; Gastanaga et al., 1998) literature samples.

However, this is taken further in the **management literature** as the nature of demand conditions, such as the regional specificity and sophistication of consumer tastes are specifically considered (Madhok, 1997; Medcof, 2001; Mueller et al., 2013). One work in the **operations and production management** literature further describes demand in terms of the demand zones within a country (Vila et al., 2006). Two articles acknowledge the specific requirements of markets or market segments such as price, service policy and availability

(Christopher and Towill, 2000; Vila et al., 2006). Attention is also paid to demand variability and its impact on risk and optimal location decisions (Baron et al., 2011; Bhatnagar and Sohal, 2005; Gebennini et al., 2009). Similar to the other literature samples, the competition in the market is explicitly acknowledged (Badri, 1999; Bhatnagar and Sohal, 2005; Chen et al., 2014; Ellram et al., 2013; Karpak and Topcu, 2010). The **innovation management** sample also highlights that R&D is not attracted to large markets per se, but by large markets that have a high degree of specificity (i.e. it is important to understand consumer tastes in that market in order to compete in the market as requirements might differ from other markets in which firms operate) (Håkanson and Nobel, 1993; Howells, 1990; Miller, 1994; Patel and Vega, 1999; von Zedtwitz and Gassmann, 2002). R&D is also particularly attracted by markets with leading consumer tastes, as this provides firms monitoring these markets with a first mover advantage if they are the first firms to anticipate a new trend or consumer demand (Gerybadze and Reger, 1999; Meyer-Krahmer and Reger, 1999). This is also linked to locating in markets where leading regulation and standard setting often takes place to ensure firms stay abreast with new developments (Gerybadze and Reger, 1999; Meyer-Krahmer and Reger, 1999).

4.4 Location related considerations

Various determinants related to the ability of firms to operate successfully at a particular location (not considering the location and properties of the market) are mentioned in the literature. This includes the presence of so called “upstream (input) linkages” or the related availability and cost of intermediate inputs, proximity to suppliers, availability of knowledgeable suppliers, cost of supplier management and quality of inputs. It also includes labour costs, the human capital available or the availability of the necessary skills (including managerial skills and semi-skilled labour). Apart from skills, labour and material inputs, other factors such as the cost of utilities and specialised support services are also mentioned. As are natural advantage (including geography, climate), the cost of capital, which includes physical capital, financial capital and the cost of land. Furthermore, infrastructure availability, quality and reliability and transport costs also influence location decisions. As do government influenced factors such as taxes, exchange rates, investment incentives, promotional activity, training grants, environmental regulation, special economic zones and trade protection. Some articles specifically study the factors that lead to the establishment of SMEs and high-tech SMEs in particular. This includes the knowledge capacity and foundational technology of a region, including the human capital and knowledge output of nearby universities and venture capital. Each of these factors are linked to their source documents in Table A.1 in Appendix A. Each of the literature fields also identify different properties of industries and/or firms that will moderate the importance of the various location determinants. These are presented in Table A.2 in Appendix A.

4.5 Interaction and dynamics

Apart from the particular market and location related factors that affect the location of economic activities, the various fields of literature samples also consider how various dynamics influence locational outcomes. The different field samples generally have different dynamics on which they focus. These are discussed at large below. The detailed references for each of the dynamics are contained in Table A.3 in Appendix A.

In the **general economics** sample, several papers focus on the interaction between demand and supply and how “snowballing” effects can lead to activity agglomeration. The outcome is moderated by transport costs which affect the interaction between demand and supply. This snowballing effect leads to the emergence of path dependence and “historical accidents” in the agglomeration of economic activities.

The **economic geography** literature aims to untangle and evaluate the importance of the different dynamics that might be driving the agglomeration effects. These papers especially focus on determinants that drive innovation – including e.g. social and economic environment and norms, education, networks, access to knowledge and IP protection. Expectations regarding these dynamic processes might even become self-fulfilling. Furthermore, agglomeration economies may lead to hysteresis i.e. large changes in comparative advantage are needed to induce changes in location agglomerations. However, when changes are large enough to induce change, this change can be dramatic.

The **general management** sample considers dynamics such as differentiation spillovers for service firms, the effect of technological progress, the contingencies that affect the impact of local experience effects, learning curve effects, the bandwagon effect (whereby companies make decisions based on limited information and mimic the behaviour of other firms), behaviours dependent on the behaviour of competitors, the development of capabilities of firms over time, the evolution of subsidiary specific roles and capabilities over time as well as the importance of uncertainty related to location decisions.

The **operations and production management** literature focusses on both expectations as well as the effect of uncertainty and risk on operations planning and profitability. The risks mentioned in the operations and production management literature sample include financial risks (e.g. exchange rate volatility), chaos risk (e.g. the bullwhip effect), regulation risk, political risk, input supply risk (in terms of quality and quantity available at a particular point in time), demand risk (e.g. planning based on under or over-estimations), intellectual property protection risk, process quality risk and reputational damage risk. The operations and production management literature sample also addresses other dynamics. In particular, the importance of expectations is once again highlighted as is the dynamic nature of locational differences over time. Finally, supply-demand interaction may impact the magnitude of holding costs, obsolescence and stock-outs. Complementing cost implications, metrics such as lead time performance, responsiveness to customer demand, quality performance, customer service level, time to market and flexibility, environmental performance and social performance are highlighted as important for sustained competitiveness.

Some articles in the **innovation management** sample align with the focus of articles in the economic geography literature sample by highlighting the positive impact of industry agglomeration on the innovative performance of firms. Others study the dynamics of apparent knowledge spillovers. These studies highlight the importance of social and human capital as well as investment in research and development for innovation and the institutional dynamics that support commercialisation of research in a country.

In the **development studies** sample, the expectations regarding corruption, bureaucratic delay and nationalisation risk are found to impact activity location.

5 Consolidated location centric analysis framework

Following the methodology outlined by Jabareen (2009), this section consolidates the key location factors identified in the review into a conceptual framework. In particular, to construct the framework we integrated concepts that have similarities into new encompassing concepts. These were then synthesised into a theoretical framework that is divided into different stages of analysis that follow one another. The framework was iteratively refined to ensure that it is internally consistent and interpretable by stakeholders.

The aim of this framework is to support the systematic evaluation of the factors affecting the location decisions of economic activities. The proposed framework is **location centric** i.e. it evaluates the performance of a location in terms of supporting a particular activity aimed at a particular market. It enables the comparison of various locations for supporting the same activity. It is therefore useful for guiding company location decisions as well as providing policy makers with a greater understanding of the key factors that affect a particular location's ability to attract and support particular economic activities.

First, an overall location centric conceptualisation of the interplay between demand (market) and supply (location) is provided. This is then further expanded upon with four phases of analysis that logically follow from one another to enable a systematic analysis of the determinants that influence the location decision of a particular economic activity. Within each phase, the key aspects for analysis are outlined in order to guide a detailed location analysis. In phase 0, before any actual investigation can be performed, the unit of analysis needs to be clearly defined. Phase 1 focuses on the market, phase 2 on the location, while phase 3 tackles the interaction and dynamics at play. Within phase 1, three sub-sections can be spelled out: (i) the definition of the market, (ii) the consumer requirements within that market and (iii) the identification of market determinants. Phase 2 defines (i) the static performance determinants as well as (ii) the factors that moderate the importance of location determinants for the different units of analysis. Phase 3 focuses on the dynamics that influence the market and location determinants over time. This naturally includes the interaction between demand and location.

5.1 Market and location

Fundamentally, the location of activities is driven by the ability to perform certain activities at a given location in order to meet the demand of customers at the same and/or other locations. For footloose multinationals, different locations for a particular activity must be compared in terms of the performance level that can be attained at different locations, and the ability to interact with and supply the targeted markets from that location. Similarly, entrepreneurs have to consider if a particular activity would be viable in the location being considered given the same considerations. This tension between performance attainable and market requirements is illustrated in Figure 1. On the one hand, different markets and market segments will be geographically separated. These markets will also have different requirements. More in particular, it can be expected that the customers within each market segment will have a particular utility function and linked demand curve that determines which and what quantity of competing outputs from the focal activity they will consume. This utility function will be a function of a variety of performance dimensions (in the case of

manufacturing, for example, this might include cost, quality, responsiveness and lead time). On the other hand, the multinational firm must weigh the performance levels that can be attained at different locations. The choice of location will also imply different effective performance levels for different markets, as the locational performance is moderated by the interaction cost with the various markets from the chosen location. Finally, a location decision and the factors affecting it is not static. Indeed, the expected changes in terms of market sizes, the utility functions of these markets, the competing firms and outputs at various locations and the changing levels of performance attainable at different locations should all be considered when evaluating the location of economic activities, as these changes and expectations surrounding these changes affect location decisions. This is also illustrated in Figure 1 (by two cross-sectional snapshots of the market-location interaction at time t and time $t+s$). The rest of this section provides a sequential analytical process for evaluating each of the components relevant to the interaction highlighted in Figure 1. The letters B₁ to B₅ refer to the different building blocks that ultimately form our consolidated framework. These building blocks are derived in (sub)sections 5.3.3, 5.4.1 and 5.5 and to be found in Appendix B.

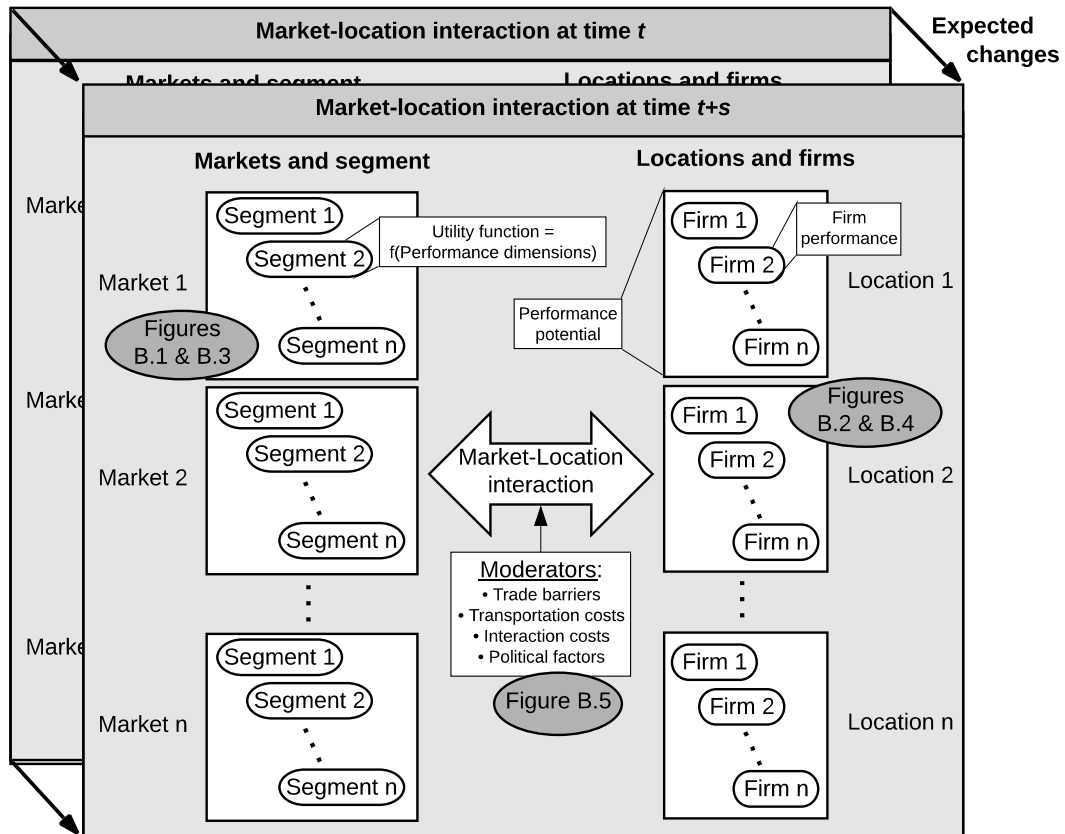


Figure 1: Dynamic interaction between market and location.

5.2 Phase 0: Setting the unit of analysis

As identified in the review section, the analysis of location determinants can take place at country, state or regional level. The actual first step towards locational decisions and the analysis of the locational determinants of an activity is, however, the clear identification of the

activity(ies) under evaluation (Gerybadze and Reger, 1999; Vila et al., 2006). This is the unit of analysis that is crucial for our framework. While some studies evaluate the location of economic activities in general, a number of studies in the review sample acknowledge the vast heterogeneity between industries (and activities within an industry) in terms of the factors that affect their location. It is therefore important to first determine (i) the industry the activity belongs to and (ii) the type of/specific firms that undertake the activity. The more detailed the definition of the industry and firms, the more insightful and effective will be the analysis of the determinants of the location of the activity. This is further considered in Phase 2 where the factors related to the type of industry and firm that alter the importance of the location determinants are considered.

To complicate matters further, studies in the review highlight that there is often an interdependency of different activities of a company. Therefore, the location of other activities of a firm (e.g. headquarters versus manufacturing versus research versus development – and the sub-components of these) and how it impacts the activities under consideration should ideally also be considered. Hence, a firm specific analysis would further increase the accuracy of the analysis, especially when considering activities that are usually performed by multi-function multinational firms. Clearly, the type of firms and/or the specific firms and the range of activities of these firms should ideally be specified before further analysis commences. Given the distinctions used in the review literature, our framework also specifically distinguishes between the requirements for manufacturing, research and development related activities.

5.3 Phase 1: Market analysis

The first phase of analysis entails the consideration of the market and segments in three steps. Firstly, the market is defined. Thereafter, the market requirements are identified. Finally, the various market determinants are considered.

5.3.1 Market definition

Once the particular activity for which the location determinants are to be evaluated has been identified, the market for these activities needs to be specified. In particular, the demand location, market size and market segments need to be specified. If the market is dominated by a few customers or even a single internal “customer” (e.g. another department within a multinational company), the analysis might be somewhat simpler. Some of the most pertinent market related considerations are outlined in Table B.1 in Appendix B for the three types of firms analysed. For manufacturing, the size of the local or regional market is of particular relevance. For development activities, the size of the market with similar tastes is of importance. For research activities, the sophistication of customers plays a larger role.

5.3.2 Market requirement definition

Once the market is defined, it is imperative to determine what consumers in the market require. In other words, for each market segment the key requirements that need to be met should be identified. This is critical if the impact of the location on the “success” of the activity is to be determined, as this is ultimately dictated by the customer segment linked to the activity (emergent from interaction between the customer’s utility and demand function and output

from competing firms). The performance metrics of interest will vary by customer segment and activity. For example, for manufacturing related activities performance on metrics such as cost, quality, service level, flexibility, lead time, responsiveness and environmental impact might be crucial, depending on the market segment being targeted. In the case of research, other metrics such as ability to consistently perform cutting edge research and protection of intellectual property might be more important metrics. Similarly, for development activities, responding to local customer requirements, including achieving rapid time to market, might be important. Furthermore, not only the current requirements per customer segment, but how these might change over the course of the planning horizon should be considered. The performance dimensions relevant to manufacturing, research and development as well as their interdependence are elaborated on in Table B.2 in Appendix B.

5.3.3 Identifying static market determinants

For governments wishing to evaluate and influence the market accessible from a particular location and for companies seeking to understand current and predict future market sizes and requirements, market determinants become important. Hence, the main market determinants identified during the review are summarised in the first static figure of our consolidated framework, Figure B.1 in Appendix B. It comes as no surprise that location factors such as per capita income, trade protection and infrastructure play a crucial role here.

5.4 Phase 2: Location analysis

Turning to the location, phase 2 addresses the determinants that influence the performance attainable at a particular location and the factors that moderate the importance of any particular determinant.

5.4.1 Identifying static performance determinants

At the location side, it is indispensable to determine the performance of the firms given the focal activity defined in phase 0. In particular, which of the determinants are most important for driving the static performance of manufacturing, research and development are outlined in the second static figure of our consolidated framework, Figure B.2 in Appendix B. It comes as no surprise that location determinants such as cost and lead time play an important role for manufacturing firms while e.g. IP regulation and skills availability are more relevant for research and development intensive firms.

5.4.2 Factors that moderate the importance of location determinants related to the type of industry and firm

As stated in phase 0, however, the type of industry and firm might influence the impact of the location determinants. Table B.2 in Appendix B summarizes the full set of moderating factors related to both the type of industry and firm that resulted from our review. For example, for an industry that has a very dynamic product environment, access to knowledgeable supporting firms will be an important location determinant while for industries that have considerable returns to scale, cost factors will matter more. Similarly, at the firm level we, for instance, find that for technologically intensive firms, skills availability will matter more. For firms with a high imitability of firm advantages, IP protection will be more important. Given

these (limited) examples it becomes obvious that the location determinants are industry- and firm-specific such that phase 0 becomes crucial when evaluating location determinants.

5.5 Phase 3: Interaction and dynamic analysis

Once the key static market and location related factors have been identified, different locations can be compared in terms of the expected performance that could be attained and hence the possible market share for which could be competed at a particular location. This requires the evaluation of the “effective performance” that each location can offer to each market given the market-location interaction moderators such as trade barriers and interaction costs highlighted in Figure 1. Furthermore, the dynamics related to both the market, location and market-location interaction should also be considered. In our framework, the dynamics identified in the review related to the market are outlined in Figure B.3 in Appendix B, those related to location in Figure B.4 in Appendix B and those related to market-location interaction in Figure B.5 in Appendix B. For example, market size and taste may change over the planning horizon due to factors such as migration and social development. Similarly, the cost of production at a particular location may, for example, change due to exchange rate changes or congestion effects from the growth of the industry. In terms of the interaction moderators, new trade restrictions may for example influence the market size accessible from a particular location. Finally, given the expected dynamics, expected performance, market and market share evaluations can be undertaken for the planning period. Based on these evaluations, firms can consider which locations provide the sought performance, cognisant of the risks and uncertainties that have been identified. Similarly, policy makers and regional planners can consider which performance metrics are likely to underperform over the planning horizon and which determinants are responsible for this underperformance. The feasibility of measures which might either address these determinants or address other determinants to compensate for the underperforming ones can then be investigated. Along with the two static Figures B.1 and B.2, the three dynamic Figures B.3-B.5 complete our consolidated location centric framework outlined in Figure 1. Together they provide an overview of static and dynamic location decision determinants – taking into account the unit of analysis.

6 Conclusion

This paper identifies the need for providing a consolidation of the myriad of location determinants that are discussed in various fields of research. In particular, such a consolidation could support the coherence of future research as well as provide companies and policy makers with a useful reference for practically evaluating the impact of various locational determinants of economic activities. Six academic fields were identified as having particular bearing on the location of economic activities. These are general economics, economic geography, general management, operations and production management, innovation studies, and development studies. Hence the top five journals in these fields were identified and a structured review of the most cited papers in these journals that meet specific search criteria was conducted. This was complemented with a further search for the most cited papers meeting the search criteria without considering the specific journals in which they were published. The final sample from these searches were then reviewed in order to determine the key location determinants

identified in these studies. These were consolidated into a novel conceptual framework that enables the systematic evaluation of the myriad factors that may affect the location of economic activities. In order to enable decision-makers in companies as well as policy makers to operationalise the location centric conceptual framework, this framework is embedded in a four-phase analytical process. However, it is clear that the importance of the different location determinants established through our approach will vary for different scenarios (sectors/firms). It is therefore obvious that depending on the sector and/or firm a government wants to attract or develop or the firm using the framework, there will be a need to focus more on a particular subset of location determinants. Our – by definition – generic tool thus provides a reference framework for industry/firm specific analytical frameworks

Our research makes various contributions to research and practice. Firstly, we make a contribution to the research literature by drawing from and integrating largely separate bodies of knowledge. Secondly, we contribute to the analytical tools used in production and operations management and the general management literature with respect to guiding firm location decisions. Thirdly, we make a contribution towards the tools in the development and economic geography literature concerned with guiding improved policy decision-making with regards to targeting key factors that may be hindering the growth of an activity at a particular location and evaluating factors that drive particular location outcomes. Finally, our synthesised framework may serve as a frame of reference for future research in each of the fields identified.

Our research serves as a first iteration of a generic framework. We hope that further research will extend and refine our contribution. Furthermore, future research is required to fully understand how the different moderating factors identified in this work influence the impact of the various location determinants on the location of particular economic activities. There is also a need for further integrating the consideration of firm emergence and growth in the framework. From a developmental perspective, policy makers may also be interested in understanding how economic activities impact regions in terms of economic, social and environmental outcomes. Adding this perspective to the current framework may also be useful. There is also a need to better understand how different policies may impact each of the identified location determinants. In particular, understanding the dependencies and feedback loops at play are important to guide optimal policy making. In summary, despite the vast literature on the location of economic activities, there is still considerable research required to untangle the various dynamics that influence the location of economic activities.

7 References

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Appendix A: Detailed review results

This appendix provides additional information relevant to the results section of the paper. In particular, Table A.1 links the location related factors described in Section 4.5 to the articles in which these factors were identified. Table A.2 links the moderating factors described in Section 4.5 to the articles in which they were identified and provides a short illustrative impact. Finally, Table A.3 links the dynamic considerations identified in Section 4.6 to the articles in which they were identified.

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Table A.1: Location related factors linked to references.

Location related factors	Reference
Upstream (input) linkages	Ellison and Glaeser, 1997; Venables, 1996.
Availability and cost of intermediate inputs	Grossman and Helpman, 2005.
Proximity to suppliers	Badri, 1999; Bel and Fageda, 2008; Bhatnagar and Sohal, 2005; Chen et al., 2014; Mair et al., 1988; Martin and Sunley, 2003.
Availability of knowledgeable suppliers	Ellram et al., 2013.
Cost of supplier management	Chen et al., 2014.
Quality of inputs	Chen et al., 2014.
Labour costs	Antràs and Helpman, 2004; Belderbos and Sleuwaegen, 2005; Cheng and Kwan, 2000; Coughlin et al., 1991; Dunning, 1998; Haug, 1985; Hennart and Park, 1994; Song, 2002.
Human capital available	Blonigen, 2005; Gennaioli et al., 2013; Hall and Jones, 1999.
Availability of the necessary skills	Amiti and Smarzynska Javorcik, 2008; Bel and Fageda, 2008; Belderbos et al., 2011; Belderbos and Sleuwaegen, 2005; Bhatnagar and Sohal, 2005; Bresnahan et al., 2001; Canina et al., 2005; Cantwell and Mudambi, 2005; Decarolis and Deeds, 1999; Dunning, 1998; Ellram et al., 2013; Haug, 1985; Hennart and Park, 1994; Martin and Sunley, 2003; Mueller et al., 2013; Rugman and Verbeke, 2001; Song, 2002.
Cost of utilities	Badri, 1999; Chen et al., 2014.
Specialised support services	Bhatnagar and Sohal, 2005; Vila et al., 2006.
Natural advantage	Ellison and Glaeser, 1997; Gennaioli et al., 2013.
Cost of capital	Bhutta et al., 2003; Chen et al., 2014; Decarolis and Deeds, 1999; Dunning, 1998; Haug, 1985; Karpak and Topcu, 2010.
Physical capital	Hall and Jones, 1999.
Cost of land	Badri, 1999.
Infrastructure availability, quality and reliability	Bel and Fageda, 2008; Belderbos et al., 2011; Bhatnagar and Sohal, 2005; Cantwell and Mudambi, 2005; Cheng and Kwan, 2000; Coughlin et al., 1991; Decarolis and Deeds, 1999; Dunning, 1998; Ellram et al., 2013; Malmberg and Maskell, 2002.
Transport costs	Badri, 1999; Bhatnagar and Sohal, 2005; Bhutta et al., 2003; Dunning, 1998; Gebennini et al., 2009; Haug, 1985; Hennart and Park, 1994; Thanh et al., 2008; Vila et al., 2006.
Taxes	Badri, 1999; Bel and Fageda, 2008; Blonigen, 2005; Chen et al., 2014; Coughlin et al., 1991; Dean et al., 2009; Ellram et al., 2013; Haug, 1985; Vila et al., 2006.
Exchange rates	Belderbos and Sleuwaegen, 2005; Bhatnagar and Sohal, 2005; Bhutta et al., 2003; Blonigen, 2005; Chen et al., 2014; Ellram et al., 2013; Haug, 1985; Song, 2002; Vila et al., 2006.
Investment incentives	Bhatnagar and Sohal, 2005; Dunning, 1998; Ellram et al., 2013; Gastanaga et al., 1998; Gray et al., 2011; Haug, 1985.
Promotional activity	Coughlin et al., 1991.
Training grants	Dunning, 1998; Haug, 1985.
Environmental regulation	Wang, 2013.
Special economic zones	Cheng and Kwan, 2000; Dean et al., 2009.
Trade protection	Belderbos and Sleuwaegen, 2005; Bhutta et al., 2003; Blonigen, 2005; Chen et al., 2014; Dean et al., 2009; Dunning, 1998; Ellram et al., 2013; Gray et al., 2011; Haug, 1985; Hennart and Park, 1994; Lael Brainard, 1997; Vila et al., 2006.
Knowledge capacity and foundational technology	Audretsch et al., 2005; Audretsch and Lehmann, 2005; Stuart and Sorenson, 2003.
Venture capital	Stuart and Sorenson, 2003.

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Table A.2: Moderating factors linked to references and illustrative impact.

	Moderating factor	Illustrative impact	Reference
Industry/product related	Complexity of production processes.	More complex industry: skills availability and experience will matter more.	Gray et al., 2011.
	Dynamism of the product market environment.	More dynamic product market: availability of knowledgeable supporting firms may become more important.	Madhok, 1997.
	How easy the type of knowledge employed is spilled over.	Type of knowledge required in industry not easily spilled over beyond clusters: location of competitors and supporting industries become more important.	Pinch et al., 2003.
	Maturity of products.	Mature products with established technologies: manufacturing costs become more important; science base becomes less important.	Barkema et al., 1996; Belderbos and Sleuwaegen, 2005; Madhok, 1997.
	Economies of scale.	Higher internal returns to scale: Cost factors play a bigger role as production takes place in fewer places and differences are magnified.	Hemart and Park, 1994; Krugman, 1991b; Storper, 2009.
	Testability of the product.	Output less testable: confidence in quality management of process (and hence antecedents of such confidence) become more important.	Gray et al., 2011.
	Existing global footprint.	Existing global footprint: considering existing sites reduces impact of other location determinants.	Chen et al., 2014.
	Experience in different regions.	Experience in region improves effective location determinants for firm in region due to experience/learning curve effects.	Hemart and Park, 1994; Song, 2002.
	Interdependence between different functions in firm.	Higher interdependence: other firm locations become more important, reducing the importance of other location determinants relevant to specific activity.	Gerybadze and Reger, 1999; Håkanson and Nobel, 1993; Howells, 1990; Kenney and Florida, 1994; Meyer-Krahmer and Reger, 1999; Miller, 1994.
	Life cycle stage of the company.	Emerging firms may have different priorities/requirements than established firms (e.g. venture capital).	Bresnahan et al., 2001; Storper, 2009.
Firm related	Size of the firm.	Smaller firms have less leverage over suppliers; thus, supplier location becomes more important.	Alcácer and Chung, 2014; Dunning, 1998; Fijjar and Rodriguez-Pose, 2011; Madhok, 1997.
	Technology intensiveness.	More technology intensive: skills availability will matter more.	Alcácer and Chung, 2014; Belderbos and Sleuwaegen, 2005; Hennart and Park, 1994.

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Table A.3: Dynamic considerations linked to references.

	Dynamic considerations	Reference
General economics	Snowball effect because of interaction demand and supply	Krugman, 1991a.
	Snowball effect because of input-output linkages	Venables, 1996.
	Empirical observation of colocation benefits or spillover effects/externalities	Ellison and Glaeser, 1997.
	Snowball effect because of human capital externalities	Gennaioli et al., 2013.
	Path dependence and “historical accidents” in the agglomeration of economic activities	Coughlin et al., 1991; Ellison and Glaeser, 1997; Head et al., 1995; P. Krugman, 1991b.
Economic geography	NEG models in general economics provide little insight in interaction between different types of agglomeration economies	Robert-Nicoud, 2005; Storper, 2009; Venables, 2005.
	Identify 3 types of agglomeration models to explain industrial clusters	Gordon and McCann, 2000.
	Social structure and institutions	Gordon and McCann, 2000; Maskell and Malmberg, 1999.
	Opportunity cost of skilled labour, education and international cooperation	Bresnahan et al., 2001.
	Cultural norms	Fitjar and Rodríguez-Pose, 2011.
	Resources at the disposal of actors which impact their access to information and knowledge as well as intellectual property protection	Maskell and Malmberg, 1999; Storper, 2009.
	Benefits accumulating from spillovers from competing firms	Mariotti et al., 2010.
General management	Rivalry in the factor and final market	Bresnahan et al., 2001; Mair et al., 1988; Martin and Sunley, 2003.
	Path dependence	Belderbos et al., 2011; Dunning, 1998.
	Localised knowledge spillovers	Alcácer and Chung, 2014; Belderbos and Sleuwaegen, 2005; Decarolis and Deeds, 1999; Dunning, 1998; Feinberg and Gupta, 2004.
	Shared infrastructure	Alcácer and Chung, 2014.
	Hysteresis and contingencies that affect the impact of local experience effects	Song, 2002.
	Differentiation spillovers for service firms	Canina et al., 2005.
	Technological progress, training costs, uncertainty modelled through a discount rate and risk expectations related to regulation	Haug, 1985.
	Learning curve effects	Barkema et al., 1996.
	Bandwagon effect	Belderbos et al., 2011; Belderbos and Sleuwaegen, 2005; Dunning, 1998.
	Behaviours dependent on the behaviour of competitors	Canina et al., 2005; Hennart and Park, 1994.
	Development of capabilities of firms over time	Cantwell and Mudambi, 2005; Decarolis and Deeds, 1999; Dunning, 1998; Madhok, 1997; McEvily and Zaheer, 1999; Rugman and Verbeke, 2001; Song, 2002.
	Evolution of subsidiary specific roles and capabilities over time	Cantwell and Mudambi, 2005; Medcof, 2001; Rugman and Verbeke, 2001.
	Exchange rate uncertainty	Belderbos and Sleuwaegen, 2005.
Operations and production management	Reduction of uncertainty through locational experience	Barkema et al., 1996; Belderbos and Sleuwaegen, 2005; Hennart and Park, 1994.
	Risk expectations related to regulation.	Dunning, 1998.
	Financial risks	Bhatnagar and Sohal, 2005; Bogataj and Bogataj, 2007.
	Chaos risk	Bogataj and Bogataj, 2007.
	Regulation risk	Bhatnagar and Sohal, 2005; Ellram et al., 2013; Gray et al., 2011.
	Political risk	Bhatnagar and Sohal, 2005; Chen et al., 2014; Ellram et al., 2013.
	Input supply risk	Bogataj and Bogataj, 2007.
	Demand risk	Baron et al., 2011; Bhatnagar and Sohal, 2005.
	Intellectual property risk	Ellram et al., 2013.
	Process quality risk	Bogataj and Bogataj, 2007; Gray et al., 2011.
Reputational damage risk	Gray et al., 2011.	
Expectations	Badri, 1999; Ellram et al., 2013.	

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	Locational differences over time	Badri, 1999; Bhutta et al., 2003; Ellram et al., 2013.
	Supply-demand interaction may impact the magnitude of holding costs, obsolescence and stock-outs	Bhatnagar and Sohal, 2005; Bhutta et al., 2003; Bogataj and Bogataj, 2007; Christopher and Towill, 2000; Gebennini et al., 2009; Thanh et al., 2008; Vila et al., 2006.
	Particular locational factors may have larger effects on locational advantages and firm performance than expected	Karpak and Topcu, 2010.
	Customer satisfaction and value	Christopher and Towill, 2000; Ellram et al., 2013.
	Profit maximisation over a short planning horizon	Baron et al., 2011; Bhutta et al., 2003.
	Lead time performance	Bhatnagar and Sohal, 2005; Chen et al., 2014; Christopher and Towill, 2000; Ellram et al., 2013; Gebennini et al., 2009; Gray et al., 2011.
	Responsiveness to customer demand	Bhatnagar and Sohal, 2005; Gebennini et al., 2009.
	Quality performance	Bhatnagar and Sohal, 2005; Chen et al., 2014; Christopher and Towill, 2000; Gray et al., 2011; Karpak and Topcu, 2010.
	Customer service level	Bhatnagar and Sohal, 2005; Christopher and Towill, 2000; Gebennini et al., 2009.
	Time to market	Bhatnagar and Sohal, 2005.
	Flexibility	Bhatnagar and Sohal, 2005; Chen et al., 2014.
	Environmental performance	Badri, 1999; Ellram et al., 2013.
	Impact on eco-system vitality and environmental health	Chen et al., 2014.
	Social performance	Badri, 1999; Ellram et al., 2013.
	Impact on equity, safety, cohesion, civil liberties and human rights	Chen et al., 2014.
Innovation studies	Impact of industry agglomeration on the innovative performance of firms	Baptista and Swann, 1998; Delgado et al., 2014.
	Knowledge spillovers through social and human capital	Tappeiner et al., 2008.
	Knowledge spillovers through investment in research and development for innovation	Love and Roper, 2001; Tappeiner et al., 2008.
	Human capital production by universities	Audretsch et al., 2005; Audretsch and Lehmann, 2005; Stuart and Sorenson, 2003.
	Institutional dynamics that support commercialisation of research in a country	Gittelman, 2006.
Development studies	Expectation regarding corruption	Amiti and Smarzynska Javorcik, 2008; Gastanaga et al., 1998.
	Bureaucratic delay	Gastanaga et al., 1998.
	Nationalisation risk	Dean et al., 2009; Gastanaga et al., 1998.

Appendix B: Framework detail

This appendix provides additional information relevant to the conceptual framework presented in Section 5. In particular, Table B.1 considers the market related considerations relevant to the three types of activities considered. Table B.2 considers the performance dimensions related to these activities. Figure B.1 addresses the location determinants relevant to the market related considerations. Figure B.2 through B.4 address the location determinants relevant to manufacturing, research and development related performance, respectively. Figure B.5 and B.6 address the dynamic factors related to the market and location, respectively.

Table B.1: Market related considerations linked to type of activity.

Subject of analysis	Market related considerations
Manufacturing	<ul style="list-style-type: none"> • Market size competitively accessible from location (considering different markets segments) • Market congruence with current markets
Research	<ul style="list-style-type: none"> • Sophistication of customers in region • Representativeness of local customer requirements of company's market
Development	<ul style="list-style-type: none"> • Size of market with similar tastes to local market

Table B.2: Performance dimensions linked to type of activity.

Subject of analysis	Performance dimensions
Manufacturing	<ul style="list-style-type: none"> • Cost • Lead-time • Flexibility • Reliability • Responsiveness • Quality • Sustainability (environmental and social impact)
Research	<ul style="list-style-type: none"> • Responsiveness to leading customer • Ability to improve the state of the art • Protection of IP
Development	<ul style="list-style-type: none"> • Responsiveness to local tastes • Protection of IP

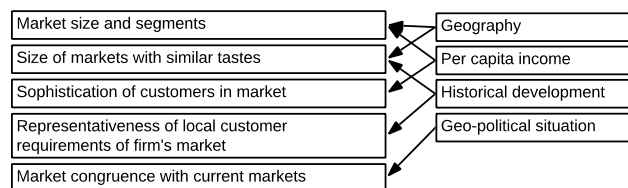


Figure B.1: Key location determinants that influence market related considerations.

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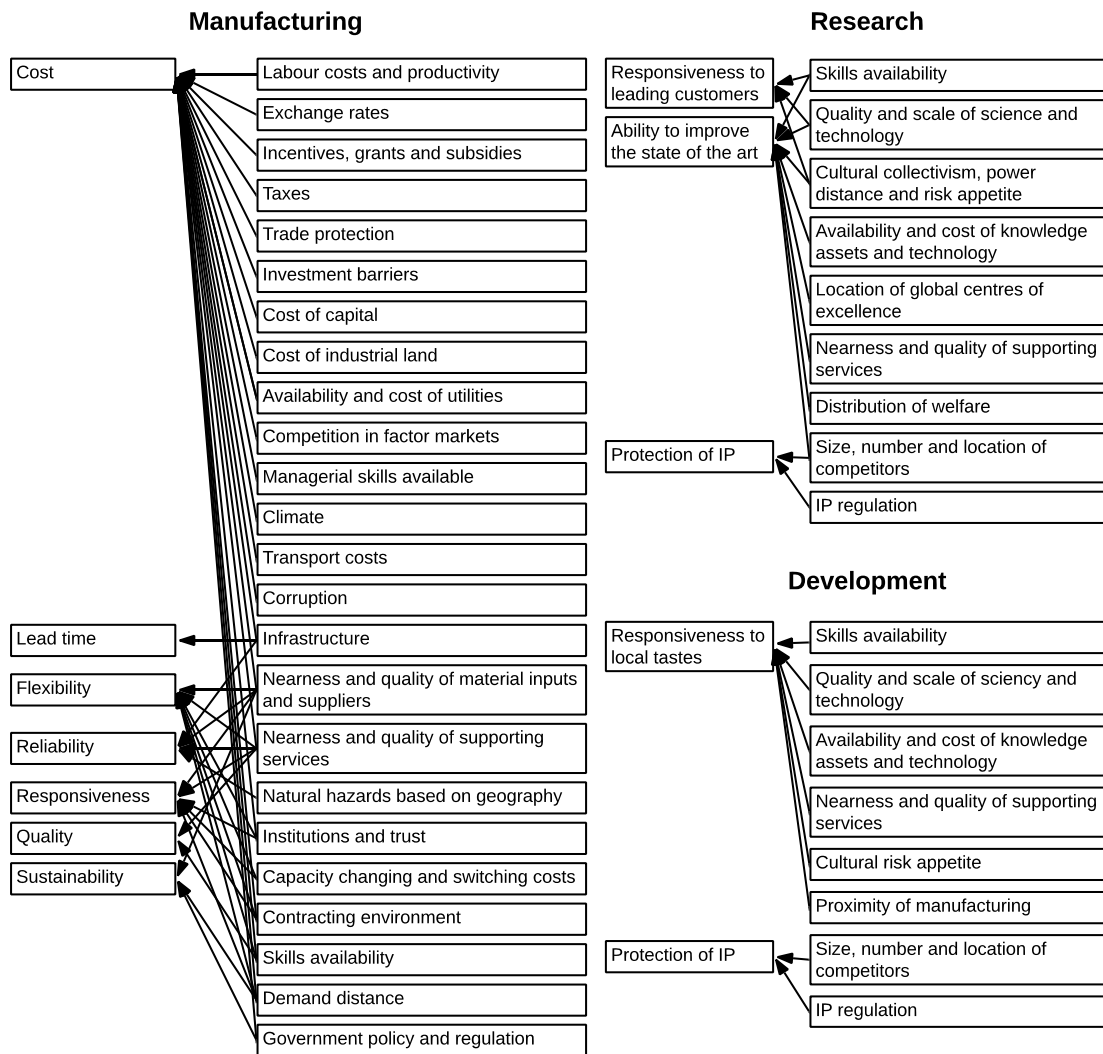


Figure B.2: Key location determinants that influence activity-related performance.

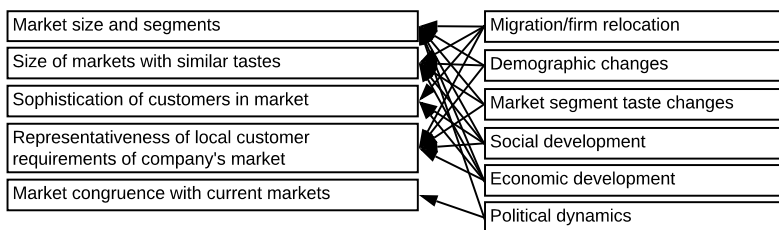


Figure B.3: Market related dynamics.

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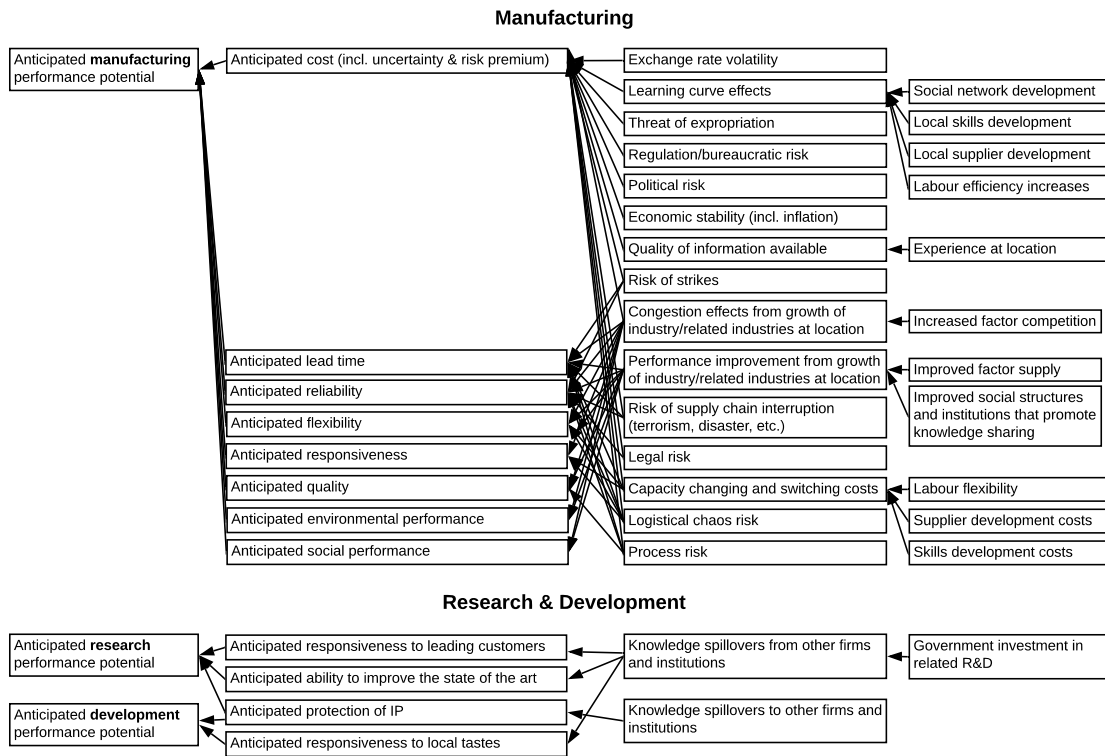


Figure B.4: Location related dynamics.

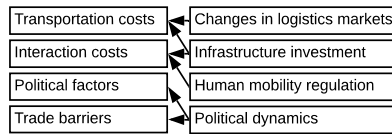


Figure B.5: Interaction moderator dynamics.

Supplementary material S1: Descriptive analysis of reviewed articles

This supplementary file provides additional descriptive information regarding the reviewed articles. In particular, Table S1.A provides a descriptive summary of the final article sample range. This is followed by a description of the methodologies employed in each literature sample, followed by a summarising table (Table S1.B).

Table S1.A: Descriptive summary of final article sample range.

	General economics	Economic geography	General management	Operations and production management	Innovation studies	Development studies
Date range of final sample	1991-2013	1998-2011	1985-2014	1999-2014	1990-2014	1996-2013
Citation range of final sample	102-3859	50-1097	27-976	52-391	54-535	60-334

In the **general economics** sample, most articles mathematically model location factors to test the theoretical implications of variations in specific factors. A number of articles also test such models using empirical data. One article took the approach of a review of the empirical literature to determine which factors have been shown to influence the location of economic activities and for which the influence is still uncertain. In the **economic geography literature** sample, a number of articles focus on the debate regarding cluster theory. Some of these provide critiques of the theoretical basis of various theoretical cluster constructs. Some papers introduce new theories or theoretical constructs, introduce mathematical models, provide empirical insights or empirically test new mathematical or theoretical constructs. The majority of articles in the **general management** sample involve theory/hypothesis generation combined with the empirical testing of these theories/hypotheses. The remainder develop theory without undertaking empirical tests, provide consolidations of the state of the art along some dimension, provide theoretical discussions of how certain factors may be conceptualised, test theory through meta analyses or provide congruence analyses of theories relating to factors that drive activity location. One article also developed a decision-support optimisation model to guide location decisions. In the **operations and production management** sample, a number of articles present optimisation models where facility location or activity allocation to facilities in different locations is one of the decision variables. Others use survey data to identify the key factors driving international location decisions, interviews to identify the importance of locational and other factors for enterprise success, empirically investigate the effect of location on quality performance or use literature reviews to develop a conceptualisation of the role of various location related factors in company performance. One article discusses different logistics paradigms and their implications for supply chain success. The majority of the articles in the **innovation management** sample mainly take a variety of theory testing approaches. The remainder focus on theory extension or empirical analyses towards the development of typologies or the identification of empirical patterns and trends. Articles in the **development literature** sample evaluate location determinants specifically with the aim of informing government policy aimed at improving developmental outcomes. Hence, the approaches followed largely overlap with those in the general economics, innovation management and

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economic geography samples, respectively. In particular, one article expanded on a theoretical new economic geography model to evaluate the impact of geography on developmental outcomes. Similar to articles in the general economics and innovation management literature samples, the majority of the articles in the development literature sample empirically evaluate the importance of different theories related to location determinants. Similar to some of the economic geography literature articles, some of the development literature articles utilise in-depth qualitative analyses of key cases. The methodologies followed by the specific articles is stipulated in Table S1.B.

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Table SI.B: Methodologies employed in each literature field sample.

	General economics	Economic geography	General management	Operations and production management	Innovation studies	Development studies
Theory building/mathematical modelling of location factors	Antràs and Helpman, 2004; Grossman and Helpman, 2005; Krugman, 1991a, 1991b; Venables, 1996.	Malmberg and Maskell, 2002; Maskell and Malmberg, 1999; Pinch et al., 2003; Robert-Nicoud, 2005; Stam, 2007; Sturgeon, 2003; Torre and Rallet, 2005. Suite and Vicente, 2009; Venables, 2005.	Medcof, 2001.			Redding and Schott, 2003.
Test mathematical/theoretical model empirically	Bloom et al., 2012; Cheng and Kwan, 2000; Coughlin et al., 1991; Ellison and Glaeser, 1997; Gennaioli et al., 2013; Hall and Jones, 1999; Head et al., 1995; Lael Brainard, 1997.	Mariotti et al., 2010; Gordon and McCann, 2000.	Alcácer and Chung, 2014; Barkema et al., 1996; Belderbos et al., 2011; Belderbos and Sleuwaegen, 2005; Bell, 2005; Canina et al., 2005; Cantwell and Mudambi, 2005; Decarolis and Deeds, 1999; Feinberg and Gupta, 2004; Hennart and Park, 1994; McEvily and Zaheer, 1999; Song et al., 2002.		Audretsch et al., 2005; Audretsch and Lehmann, 2005; Baptista and Swann, 1998; Cantwell and Vertova, 2004; Colombo and Delmastro, 2002; Delgado et al., 2014; Gittelman, 2006; Guellac and Van Pottelsberghe De La Potterie, 2001; Kenney and Florida, 1994; Kessler and Chakrabarti, 1999; Löfsten and Lindelöf, 2003, 2002; Love and Roper, 2001; Petruzzelli, 2011; Stuart and Sorenson, 2003; Tappeiner et al., 2008.	Amiti and Smarzynska Javorcik, 2008; Dean et al., 2009; Démurger, 2001; Gastanaga et al., 1998; Kumar, 1996; Wang, 2013.
Empirically driven		Bel and Fageda, 2008; Bresnahan et al., 2001; Fijjar and Rodriguez-Pose, 2011; Mair et al., 1988; Wei et al., 2007.		Bhatnagar and Sohal, 2005; Ellram et al., 2013; Karpak and Topcu, 2010; Gray et al., 2011.	Håkanson and Nobel, 1993; Meyer-Krahmer and Reger, 1999; Miller, 1994; Patel and Vega, 1999; Silvestre and Dalcoi, 2009; von Zedtwitz and Gassmann, 2002.	Frigant and Lung, 2002; Larsson, 2002.
Review of literature/theoretical consolidation	Blomigen, 2005.		Dunning, 1998; Mueller et al., 2013; Rugman and Verbeke, 2001.	Chen et al., 2014.		
Theoretical critique/discussion		Henry and Pinch, 2001; Martin and Sunley, 2003; Storper, 2009.	Madhok, 1997.	Christopher and Towill, 2000.	Christensen, 1995; Gerybadze and Reger, 1999; Howells, 1990; Iannarino and McCann, 2006.	
Decision-support/optimisation model			Haug, 1985.	Badri, 1999; Baron et al., 2011; Bhutta et al., 2003; Bogataj and Bogataj, 2007; Gebennini et al., 2009; Thanh et al., 2008; Vila et al., 2006.		

7.3 Conclusion: Chapter 7

This chapter reviews the factors that influence the location of economic activities. These factors are then consolidated into a conceptual framework and supporting analytical process to guide the systematic evaluation of location determinants for a particular activity. This thus directly addresses the third and final objective of this dissertation, namely, to “develop a new analytical framework that enables the appraisal of the factors driving the location of particular downstream mineral processing activities to understand how such activities could be targeted (and thus attain a first approximation of the cost and feasibility of doing so)”. This is the last chapter that directly seeks to address any of the research objectives. The next chapter summarises and concludes the dissertation.

Chapter 8

Conclusion

This chapter concludes the dissertation by summarising the research presented (Section 8.1) and highlighting its scientific (Section 8.2) and practical (Section 8.3) contributions. It also contains recommendations for future research (Section 8.4).

8.1 Summary

The dissertation consists of a number of chapters. Chapter 1 provides an introduction to and overview of the dissertation. This includes stipulating the research aim and three primary objectives of the dissertation. Chapters 2 to 7 each seek to contribute to addressing one of the three research objectives as indicated in Figure 8.1. Chapters 2 to 7 each also contain a published or unpublished article.

In Chapter 1, the primary aim of this dissertation is stated as being: “frame the debate regarding beneficiation (downstream linkages from mining) and, based on this framing, to develop new analytical tools to facilitate improved beneficiation related policy-making”. Further, the three objectives identified to support this aim are to:

1. develop a conceptualisation of mineral value chains that frames the beneficiation debate and enables a holistic contextualisation of downstream mineral processing policy;
2. develop new/adapted analytical frameworks that provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities; and
3. develop a new analytical framework that enables the appraisal of the factors driving the location of particular downstream mineral processing activities to understand how such activities could be targeted (and thus attain a first approximation of the cost and feasibility of doing so).

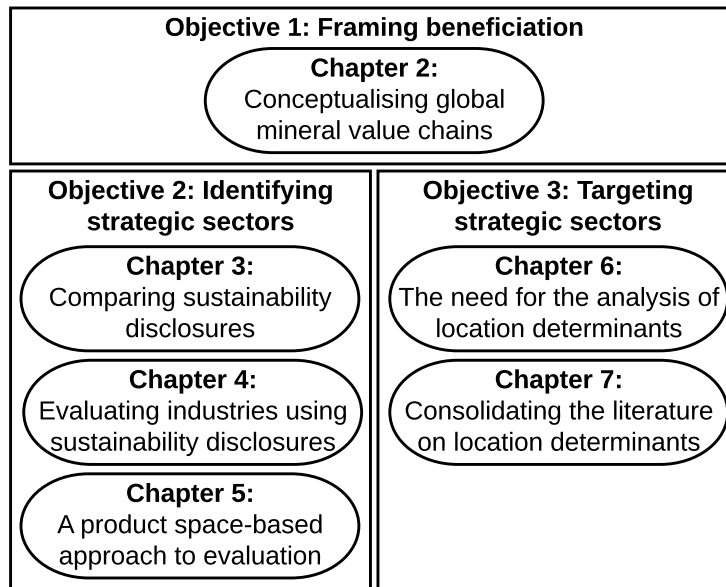


Figure 8.1: Overview of each chapter's relation to the three objectives.

Toward the attainment of the first objective, Chapter 2 presented a novel framework for conceptualising mineral value chains and framing the beneficiation debate in a holistic manner. This was followed by the chapters that relate to the second research objective (Chapter 3 to 5). These were thus concerned with exploring analysis avenues that might provide improved insight regarding the potential strategic value of pursuing different downstream mineral processing activities. Chapter 3 and 4 form a unit. They specifically evaluate the use of public sustainability disclosures for comparing the potential strategic value of different industries. The framework presented in these chapters was found to hold potential, but to still be restricted by the limitations inherent in the underlying sustainability disclosures. It is expected that these will be reduced, however, as sustainability disclosures continue to improve.

This was followed by Chapter 5, which presented a framework with a similar aim, but which used a different departure point. In particular, the chapter introduced a novel input-output product space (IO-PS) analysis approach that extended the product space work by Hidalgo *et al.* (2007) to make it useful for assessing specific opportunities in mineral value chains. The chapter also used the case of steel in South Africa to reflect on the beneficiation debate on a more theoretical level. In particular, it was found that the beneficiation narrative seems to be supported by the data at a high level of analysis. However, when considering the value chain at a product category level, it becomes apparent that a more nuanced “leap-frogging” approach to development may be more optimal than a strict step-wise beneficiation approach to development.

Both of these frameworks (the disclosures-based framework and IO-PS framework) thus addressed the second research objective and imply differ-

ent strengths and weaknesses. Both present important contributions to the suite of tools available to decision-makers to evaluate mineral industries (and product-based industries in general) in terms of their contribution to different strategic objectives.

Chapters 6 and 7 explore how countries may appraise the mechanisms driving the location of a particular activity in order to understand how such an activity could be targeted and thus attain a first approximation of the cost that would be linked to such interventions. Chapter 6 identified why there is a need for understanding location determinants in order to better inform downstream mineral processing-related policy. Chapter 7 investigated the key factors that may affect the location of economic activities in general, and by implication, mineral related activities. These factors were then used to construct a framework that may be used to systematically evaluate the factors affecting the location of a specific activity and which mechanisms policy-makers may be able to employ to influence the location of such an activity. This then provides policy-makers with a first approximation of the cost and feasibility of targeting the focal industry for development.

8.2 Scientific contribution

The research presented in this dissertation is particularly significant given the broad and deep multidisciplinary nature of its approach to tackling important policy questions that relate to the development of countries and mineral-rich developing countries in particular. It sought to combine from and contribute to insights from fields as diverse as operations management, development studies, economic geography, political economy, accounting and environmental studies. In this manner, the study contributed toward holistic policy analysis frameworks that aim to bridge these fields in order to support future multidisciplinary research and provide new insights. Some of the most important contributions to the scientific body of knowledge derived in the course of this research include:

1. exploring how mineral value chains may be conceptualised to support policy formation;
2. evaluating sustainability disclosures for their potential to support the analysis of industries for industrial policy formation;
3. adapting the product space approach to enable the analysis of value chains and product categories;
4. critiquing the beneficiation narrative by evaluating the theoretically optimal route of development from a product space perspective;

5. highlighting the importance of a holistic understanding of location drivers for supporting optimal development policy formation; and
6. developing a framework (that is rooted in a multi-disciplinary review of location determinants) of factors that drive the location of economic activities to enable an appreciation of the interventions that might be required for supporting the economic viability of a given economic activity in a particular location.

8.3 Implications for practice and policy

In line with the aim of this research, the dissertation contributed a novel framing of the debate regarding beneficiation (downstream linkages from mining) and, based on this framing, explored the use of analytical tools in order to facilitate improved beneficiation related policy-making. In particular, the research contributed to three types of policy tools with different aims, namely, to support:

1. the conceptualisation of mineral value chains to enable the analysis of downstream mineral policy;
2. the appraisal of the strategic value of different downstream processing activities in order to prioritise policy attention and to derive an appreciation of the possible value of attaining any particular processing industry (this was achieved by making use of a sustainability disclosure perspective and product space perspective); and
3. the understanding of how strategic activities may be targeted and thus attain a first approximation of the cost that would be linked to such interventions.

It is envisioned that the combination of the proposed tools in these three categories will support improved future policy decision-making with regards to mineral value chains and development in general, particularly in mineral-rich developing countries. Figure [8.2](#) provides a pictorial summary of the key policy tools developed in each part of the dissertation.

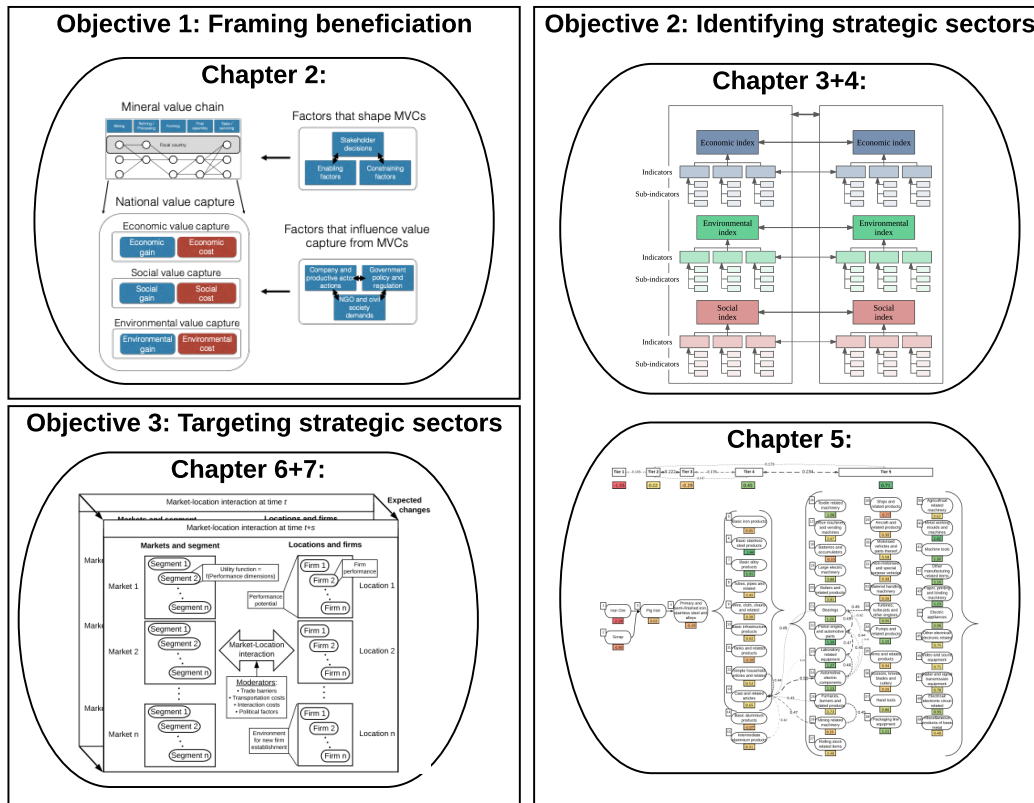


Figure 8.2: Pictorial summary of the key policy tools developed in each part of the dissertation.

8.4 Suggestions for future research

During the execution of this research, various avenues for future research were uncovered. These can be linked to the three objectives of this research, as well as the methodological approach of this research. In particular, a number of avenues for research related to the conceptualisation of mineral value chains can be identified. Firstly, this research focussed on the downstream linkages from mining. However, upstream linkages have been increasingly highlighted in literature as a promising avenue for development that may be more readily attainable than downstream linkages. Thus, more explicitly including upstream linkages in the conceptualisation of mineral value chains is an important avenue for future work. Secondly, untangling the roles, incentives and value capture linked to the various stakeholders involved in the mineral value chain appears to be an important avenue for future research. This includes integrating the power relations that are central to the GVC/GPN literature into the conceptualisations presented in this research.

A number of opportunities for future research were also identified in terms of the literature pertaining to identifying strategic sectors for development. Firstly, as identified in Chapter 4, there is still considerable work required

to improve sustainability disclosures to ensure they can better support triple-bottom-line industry analysis. Secondly, the product space approach that underpins Chapter 5 can be further refined. In particular, the assumptions such as the binary nature of the revealed comparative advantage, the inability to forecast changes of the product space and the unstable nature of the complexity index over time are key aspects that require further research. Furthermore, the IO-PS approach can be extended beyond the single steel value chain to consider more aspects of the economy concurrently. The brute-force optimisation approach used in Chapter 5 will then become inadequate. Hence, more sophisticated optimisation algorithms would need to be combined with the IO-PS framework to enable such extended dynamic analyses. It would also be useful if the IO-PS approach could explicitly be extended to include other triple-bottom-line dimensions.

In terms of the third aim of this research, future research can explore the practical implementation of the suggested framework in Chapter 7. In particular, it would be interesting to compare the results emerging from such a study with the barriers that were inductively identified for the manganese industry by Van Zyl *et al.* (2016) in a study linked to this dissertation. Furthermore, the proposed framework in Chapter 7 could be used in future studies evaluating the difference in the importance of the various location determinants for the different classes of mineral processing activities. Given these differences, the feasibility of intervening in these value chains and suites of policies that could be linked to supporting these mineral-related industries could be identified.

In relation to the methodology of the research, the cases used for illustrating and testing the frameworks that aim to support the evaluation of the strategic value of developmental industries were all focussed on South Africa. Therefore, more research is required to evaluate the generalisability of the approaches to other developing countries. In particular, the lack of data for smaller economies would hamper the application of the developed methodologies to such countries. Further research might also explore whether this shortcoming could be addressed by estimating missing data based on the data from other similar countries.

Finally, this research contributed towards addressing the analytical gaps that existed in the literature in terms of analysing: i) the strategic value of different mineral related industries; and ii) the feasibility of targeting such industries by identifying the key determinants that drive the location of these activities. In so doing, the research exposed further knowledge gaps in terms of identifying the strategic value of industries and how to target them more generally. Hence, the results of this research could be extended beyond only the mineral industry, which was the focus of this study, to the general realm of industrial policy-making.

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Appendices

Appendix A

A global value chain sustainability analysis framework

This appendix highlights how the concepts presented in the framework presented in Chapter 2 might be incorporated in the existing global value chain frameworks. This was viewed as important in order to further contextualise the unique aspects of the proposed framework. The paper was published in the peer-reviewed *Southern African Institute for Industrial Engineering's 29th Annual Conference Proceedings* as follow up to the article presented at the Southern African Institute for Industrial Engineering's 28th Annual Conference (presented in Chapter 2). The article presented in this appendix is the peer-reviewed version published in these proceedings. The full proceedings are available at: <http://www.saiie.co.za/cms/attachment/740>.



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**PROPOSING A GLOBAL VALUE CHAIN SUSTAINABILITY ANALYSIS FRAMEWORK:
TOWARD THE ANALYSIS OF REGIONAL VALUE CAPTURE**

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ABSTRACT

Global value chain (GVC) analysis has been increasingly used in the field of development studies. This article identifies three specific weaknesses of this methodology: the lack of concurrent consideration of economic, environmental and social elements concurrently; measuring only relative impact, instead of absolute impact; and a limited scope that excludes externalities and regional impacts. To address these weaknesses, the article proposes a global value chain sustainability (GVCS) analysis approach that includes a local value capture dimension. The value of this proposed approach is shown by applying it to the example of the mineral resources industry.

OPSOMMING

Globale waardeketting (GWK) analise word al hoe meer gebruik in die veld van ontwikkelingstudies. Hierdie artikel identifiseer drie spesifieke swakpunte van hierdie metodologie: ekonomiese, omgewings en sosiale elemente word nie saam geanaliseer nie, slegs relatiewe impak, in plaas van absolute impak, word gemeet; en dit is 'n beperkte fokus wat eksternaliteite en streeksimpakte uitsluit. Om hierdie swakpunte aan te spreek, stel hierdie artikel 'n uitgebreide globale waardeketting volhoubaarheid (GWK) analise benadering voor wat 'n plaaslike waarde toevoeging dimensie insluit. Die waarde van hierdie voorgestelde benadering, word gedemonstreer deur dit toe te pas op 'n voorbeeld vanuit die minerale hulpbronne industrie.



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1. INTRODUCTION

Nations are becoming increasingly focussed on not only “inserting” themselves into global production networks, but also ensuring that they capture more value from the activities in which they are involved. As such, there is increasing emphasis on ensuring that economic activities do not only provide economic benefits to their host nations, but also enable social upliftment and ensure environmental sustainability.

Within this context, there exists a need for tools to support the evaluation of how countries and regions capture value from their participation in global value chains and how different policy options may affect this value. Such tools should provide a holistic triple bottom line (TBL) perspective (thus including economic, social and environmental concerns) and consider the global contexts within which policies are situated.

One promising tool that has been increasingly used within organisations that consider development within a global context is global value chain (GVC) analysis [1]. There have also been attempts to extend GVC analysis to better address the TBL elements through the introduction of the concept of “upgrading”, for example [2]. However, these generally only include one or two of the TBL elements. Furthermore, they generally only refer to relative improvements and have not succeeded in providing an integrated and holistic TBL adaptation of GVC analysis that also allows the measurement of the absolute impact of value chains. These extensions also generally include a relatively narrow scope, thereby not considering indirect impacts and regional concerns. Towards addressing these shortcomings, this article proposes the addition of a “value capture” analysis dimension to the traditional GVC analysis framework as conceptually proposed by Henderson et al. [3] in the global production network literature. Building on [3], we show how this can be practically added to the GVC framework. The resulting analysis framework is intended to enable the inclusion of all three elements of the TBL in the analysis of global value chains. This is done by allowing for the consideration of absolute impact and by allowing for the inclusion of indirect and regional impacts of the value chain. The mineral resources industry is used as an example to illustrate the benefit of the inclusion of the “value capture” dimension in the extended framework vis-à-vis the traditional GVC approach and literature.

The main advantage of the proposed operationalisation of the value capture dimension is that it provides an explicit way of indicating the sustainability impact of particular activities that form part of the global value chain. We thus refer to the extended framework proposed in this paper as the *global value chain sustainability* (GVCS) framework to acknowledge the root of the framework, but also emphasise the proposed addition.

The next section (Section 2) presents an overview of the existing GVC analysis frameworks and their shortcomings in relation to the inclusion of the TBL elements. This is followed by Section 3 which defines and contextualises the proposed “value capture” analysis dimension. Section 4 presents the mineral industry example. Finally, Section 5 contains the conclusion to the article.

2. GLOBAL VALUE CHAIN ANALYSIS

The GVC analysis framework originated in the global commodity chain (GCC) literature of Gereffi and Korzeniewicz [4] and Gereffi [2]. Gereffi [2] identified that GCCs, consist of four primary dimensions: (1) the input-out structure; (2) geographical dispersion of activities; (3) governance structure between firms; and (4) the institutional context both at a national and international level.

Gereffi [5] and Humphrey and Schmitz [6] extended these four dimensions by also establishing the concept of “upgrading”. Gereffi [5] identified that developing nations can insert themselves into global value chains and incrementally “upgrade” to capture more of the value chain and more value from the value chain. Typically, this will entail entering the value chain with competitive labour-intensive low-skilled operations and gradually moving into higher-skilled areas of the value chain.

Humphrey and Schmitz [4], building on the work of Gereffi [5], identified four types of upgrading in GVCs: *process upgrading*, referring to “transforming inputs into outputs more efficiently”; *product upgrading*, referring to “moving into more sophisticated product lines”; *functional upgrading*, referring to “acquiring new functions (or abandoning existing functions) to increase the overall skill content of activities”; and *inter-sectoral upgrading* (also known as chain upgrading), that happens when “firms of clusters move into new productive activities”.

This concept of “upgrading” thus specifically refers to the type of activities countries are involved in. Its introduction added a temporal dimension enabling the analysis of how local participation in GVCs evolve over time. However, it does not address the continual impact that these activities have on the host regions and rather view any change to higher skills and more of the value chain as a beneficial change for the host region. It thus



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focuses on relative improvements along specific dimensions, instead of measuring absolute performance or impact across multiple dimensions.

More recently, as the awareness regarding sustainability has grown, the concept of “upgrading” has also been extended to include both social and environmental elements more explicitly. For example, Barrientos et al. [7] have made a notable contribution in terms of *social upgrading* in GVCs. They defined social upgrading as denoting the process of improvement in the rights and entitlements of workers as social actors, which enhances the quality of their employment. As such, they identify three types of social upgrading in GVCs: *small-scale worker upgrading*, referring to where workers “remain within home-based production (agriculture or manufacturing), but are able to enjoy improvements in their working conditions”; *labour-intensive upgrading*, referring to where workers “move to better types of labour-intensive work where they can also obtain better working conditions”; and *higher-skill upgrading* where workers “move towards better types of paid employment associated with progressive social upgrading”.

Building on the work by Barrientos et al. [7], Gereffi and Lee [8] also make a contribution in terms of social upgrading by drawing from the industrial clusters literature. They highlight six pathways for social upgrading and suggest the importance of what they term “synergistic governance”. They also highlight the need for linking economic and social upgrading from the perspective of the GVC and cluster literature.

Similar to the relative nature of the original economic conceptualisation of upgrading, all these definitions of social upgrading place a primary focus on the workers directly involved in production activities. In the process, these conceptualisations do not extensively take account of the external effects of productive activities on surrounding communities, societies and those external to the direct activities of the value chain. Furthermore, these conceptualisations also have a focus on relative improvement and do not include the ongoing impact of activities.

Research linking environmental concerns to the GVC analysis framework has been less prevalent. Nonetheless, De Marchi et al. [9] leverage the governance focus of the traditional GVC literature and identify two governing approaches that lead firms can follow that can lead to “greener” value chains (*standard-driven* and *mentoring-driven*). Similar to the other applications of “upgrading” in the GVC literature, the work of De Marchi et al. [9] emphasises some change of the GVC from one state to another, without regard for the absolute impact of the current or future state of the value chain on the environment.

It thus appears that one key weakness of the “upgrading” approach employed in the GVC literature to address triple bottom line (TBL) aspects, is that it does not inherently assess the absolute impact of the existing or future state of the value chain. Instead, “upgrading”, as used in the GVC literature, refers to an improvement on or extension of a previously existing state and such extension of or improvement on is viewed as an inherently positive development, irrespective of the original state and its ongoing impact.

The current GVC literature also generally restricts the scope of focus to a relatively narrow view that does not consider the direct and indirect impacts of the value chain activities beyond the borders of the firms involved in the specific value chain. It thus excludes the possible positive and negative externalities that might result from participation in the value chain.

Finally, the current GVC analysis literature generally only addresses one or at most two of the TBL elements in any one analysis framework. This leads to the risk of underestimating or not being aware of specific trade-offs that might be present between the different TBL elements during analysis.

This article aims to address these three shortcomings of GVC analysis by introducing and defining an additional “local value capture” dimension within the GVC analysis framework. The resulting framework may be regarded as a global value chain sustainability (GVCS) analysis framework. This “local value capture” dimension is defined in the next section (Section 3). Thereafter, the value of the GVCS approach is illustrated through the use of an example, presented in Section 4.

3. CONCEPTUALISING NATIONAL VALUE CAPTURE WITHIN THE GVC

The elements of the traditional GVC analysis framework, along with the related concept of “upgrading” is represented in Figure 1.



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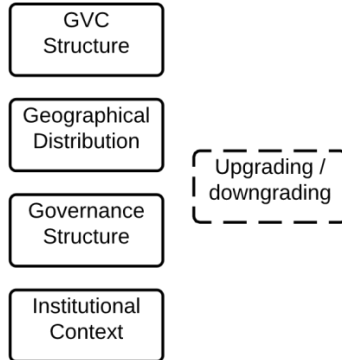


Figure 1: The elements of traditional GVC analysis.

To enable the conceptualisation of national (or regional) value capture, it is necessary to establish the activities that form part of the GVC under consideration that currently take place within a focal region or country. This is referred to here as the “local footprint” and is a function of the GVC structure and the geographical distribution of this structure. This local footprint then translates into a specific local value capture for the focal region as shown in Figure 2. It is proposed that the value that is captured from the local footprint can be conceptualised according to the three sustainability elements of the TBL concept, popularised by Elkington [10]. Each of these elements can also be conceptualised as entailing gain and cost, as the complex impacts of activities can have both positive and negative effects on the host nations, as will be illustrated in the example in the following section. This conceptualisation enables the evaluation of the current impact of the value chain on the host region. This impact implied by the local value capture dimensions enables an absolute measurement of the impact of GVC activities within a region. For example, the economic gain of an economic activity can be measured in contribution to GDP or employment. Similarly, environmental cost can be measured by evaluating the carbon footprint of the activity. The value capture element thus allows the direct linking of impact to activities. The specific impacts measured in a study will depend on the goals and design of the study, but the suggested framework provides a framework for including such measures.

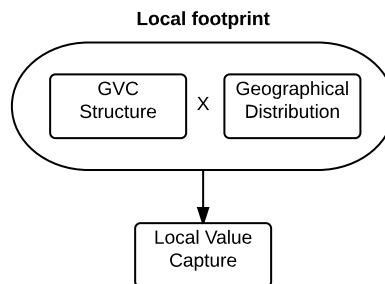


Figure 2: A conceptualisation of value capture within the GVC framework.

Upgrading then refers to a change in the local footprint in a focal region (e.g. when a company relocates a factory into a region, the local footprint of that activity in the location located to increases) or a change in the translation of this footprint to value for the region (e.g. when a multinational company increases the wages it offers the workers within a country). This relationship between value capture and upgrading is illustrated in Figure 3. It indicates that upgrading can be considered to be the change in the local footprint or value capture between different longitudinal states of the same local value chain at two points in time (these points are shown as T_0 and T_1). The inclusion of all three dimensions of the TBL enables the appreciation of the trade-offs that the change of footprint might imply. For example, the introduction of a new activity might lead to improved economic results for a region, yet will likely also increase the environmental degradation in the region. Furthermore, this new activity might have a stabilising or disruptive effect on the social fabric in this region. This broader view is crucial for policy makers to appreciate the trade-offs that any policy decision invariably entails.

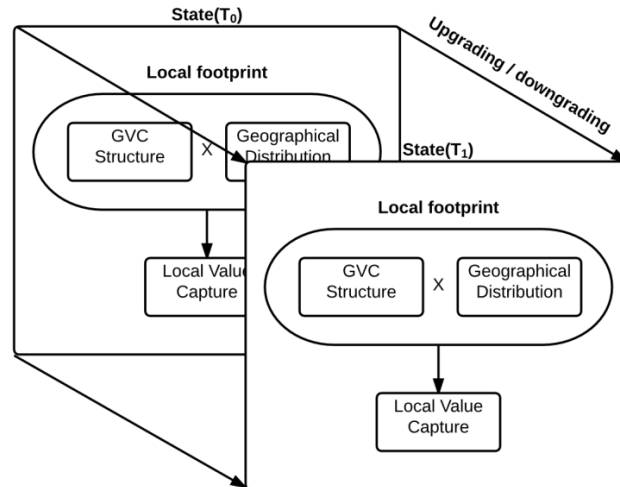
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Figure 3: The relationship between value capture and upgrading

4. MINERAL RESOURCES EXAMPLE

To illustrate the benefit of the proposed GVCS framework an example of the factors that may be considered in the mineral resources industry is presented. The example aims to illustrate the additional TBL impacts that can be included in analysis when using the GVCS framework vis-a-vis the existing GVC analysis frameworks. The example is based on a review of the 304 articles published in the journal *Resources Policy* since the start of 2010 up until 12 July 2015. These articles were analysed to identify potential impacts (value capture) of mineral resources related activities on host regions (Table 1 to 5). These impacts were then categorised according to whether they are likely to fall within the general scope of existing GVC analysis frameworks or whether they would likely only be considered under the broader GVCS analysis framework proposed in this article (Table 6).

Table 1 and 2 indicate the positive and negative economic value capture impacts identified from the review. Table 3 and 4 do the same for the social element of the TBL. As far as minerals and the environment is concerned, the focus in literature and elsewhere is generally on minimising the negative impacts on the environment. Therefore, Table 5 indicates only the negative environmental value capture impacts identified. In the review, one positive impact was identified, namely, the creation of man-made habitats for protected birds [11] (#41). The results of the analysis regarding whether each of the identified impacts will likely fall within the scope of the existing GVC analysis framework or only in that of the extended GVCS analysis framework, is shown in Table 6. The categorisation of specific identified aspects may be disputed in either direction, but the overall results, and subsequently, the clear value of the GVCS approach, is robust.

SAIE28 Proceedings, 25th - 27th of October 2017, Riverside Sun, South Africa © 2017 SAIE**Table 1: Identified impacts: positive economic value capture**

#	Impact	Source
1	Appreciation of the national currency	[12]
2	Capital investment	[12-14]
3	Diversification of exports	[15]
4	Economic growth	[12]
5	Employment in other sectors	[16-19]
6	Employment sustained	[12, 14, 16, 18, 20, 21]
7	Local value added	[20]
8	Lower inequality	[21, 22]
9	Improved income levels	[12, 14, 18, 21, 23]
10	Infrastructure development	[13, 24]
11	Other linkages	[1, 2, 12, 14, 25-35]
12	Shareholder returns	[12]
13	Tax revenue	[12, 18, 36-38]

Table 2: Identified impacts: negative economic value capture

#	Impact	Source
14	Exhaustion of minerals	[12]
15	Low job spillovers into manufacturing and agriculture	[17]
16	Opportunity cost	[12, 17]
17	Outflow of revenue to foreign investors	[39]
18	Poorer financial development	[40]
19	Possible slower national economic growth	[41]
20	Regional economic problems such as low entrepreneurial activity, pressure on local services and infrastructure, specialisation on minerals and unaffordable housing	[12, 42, 43]
21	Resource dependence of the economy which may lead to the crowding out of other sectors, instability and insecurity due to the dependence on the fluctuating external demand	[12]



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Table 3: Identified impacts: positive social value capture

#	Impact	Source
22	Better education	[23]
23	Improved communication access	[23]
24	Improved income levels	[12, 18, 23, 44]
25	Increase in disease prevention initiatives	[45]
26	Lower unemployment	[21]
27	More equitable distribution of income	[18]
28	Reduction in poverty	[46]

Table 4: Identified impacts: negative social value capture

#	Impact	Source
29	Conflict	[36, 41, 47]
30	Corruption	[41, 48]
31	Human rights suppression	[49]
32	Inequality	[41]
33	Poorer education	[12]
34	Poor working conditions	[42]
35	Rentier states	[41]
36	Risks to human health	[49-51]
37	Stranded regions	[12]
38	The aggravation of societal issues through the white washing effect of corporate social responsibility	[52, 53]
39	The displacement and relocation of communities	[36, 54, 55]
40	The disruption of traditional cultures	[52]

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#	Impact	Source
42	Air quality degradation	[59, 56]
43	Deforestation	[42]
44	Degraded recreational resources	[57]
45	Ecosystem degradation	[50, 57]
46	Erosion	[42, 57]
47	General environmental degradation	[41, 48, 49]
48	Heavy metal contamination	[49]
49	The introduction of non-native species	[57]
50	The loss of fauna	[52]
51	The loss of habitats for fauna	[57]
52	Risks to clean water supplies	[56, 57, 41]
53	Toxic spills	[49]
54	Visual degradation	[56]

Table 6: Classification of identified impacts

	Likely to be captured by existing GVC analysis frameworks	Likely only to be captured by extended GVCS analysis framework
Economic gain	2,4,6,7,9	1,3,5,8,10,11,12,13
Economic cost		14,15,16,17,18,19,20,21
Social gain	24,26,28	22,23,25,27,29
Social cost	31,34	29,30,32,33,35,36,37,38,39,40
Environmental gain		41
Environmental cost		42,43,44,45,46,47,48,49,50,51,52,53,54

The tables indicate that the existing GVC analysis frameworks addressed only ten of the fifty-four impacts identified. This included five of the thirteen economic gains identified, three of the seven social gains identified, two of the twelve social costs identified and none of the economic costs, environmental gains or environmental costs identified. The example highlights the ability of GVCS analysis to incorporate all three dimensions of the TBL in one holistic framework. It also broadens the scope of the impacts assessed beyond the boundaries of the firm. This makes the framework more useful for policy makers that need to also consider possible externalities. This broader scope also allows for the integration of regional concerns in the analysis, something that has thus far been lacking in GVC analysis framework. By adding the value capture dimension to the GVC framework, the GVCS framework allows for the consideration of any number of absolute impacts of activities. This then adds to the current limited focus on relative improvements afforded by the exclusive use of “upgrading” as an analysis dimension

The extension thus addresses the three weaknesses of the existing approach identified in the literature review. Firstly, it enables the assessment of the absolute impact by reviewing the TBL impact explicitly and not just the change in the impact under the form of “upgrading”. Secondly, the value capture dimensions as proposed in this article allows for the consideration of externalities that are not limited to the firm executing the activities. This includes impacts such as erosion and corruption. Finally, the framework allows for the concurrent evaluation of all three TBL dimensions, thus providing for the evaluation of the trade-offs between the dimensions that may be inherent in changes to the GVC.

5. CONCLUSION

The article presents an overview of existing GVC analysis frameworks and their shortcomings in addressing the TBL elements. Three specific weaknesses of the common “upgrading” approach to evaluating the TBL elements



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were identified. Firstly, the upgrading approach only focusses on relative impact improvements and does not enable the consideration of absolute impacts occurring due to GVC participation. Secondly, the general scope employed in the GVC literature is generally limited to the impact on the firm(s) directly involved in a particular GVC within a narrow perspective. Thirdly, the existing frameworks generally focus on only one or two elements of the TBL. This then excludes the analysis of externalities and regional aspects of GVC impacts. The article thus proposed a global value chain sustainability analysis approach that includes a local value capture dimension and contextualises this in relation to “upgrading”. The article then illustrates the value of this proposed approach through applying it to the example of the mineral resources industry. The example highlights the additional TBL impacts that can be considered when applying the GVCS analysis approach vis-à-vis the traditional GVC literature. Based on the results, it is concluded that the proposed GVCS analysis framework addresses all three identified weaknesses of GVC analysis. The GVCS approach thus extends the existing approach to provide a broader, more flexible tool with which to analyse the impacts of various GVCs and enables the analysis of various policies that aim to attain better TBL outcomes for a particular region or country.

Further work is needed to further test and refine the proposed approach. This could take various forms, including specific case study applications using the approach and comparing the outcomes to the traditional GVC frameworks. The article has focussed on the structure, geography, local value capture and upgrading within GVCs. Further studies could evaluate what effect, if any, the use of the GVCS analysis framework has on the evaluation of the institutional context and governance structure of value chains.

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Appendix B

Contribution declarations

This appendix contains the declarations of PhD candidate and his co-authors regarding the nature of the contribution that each author made to each of the included articles. In order to keep the signatures of individuals out of the public domain, the declarations are included in the dissertation without signatures. The signed declarations are in possession of the candidate and primary supervisor at Stellenbosch University (Prof Corne Schutte).

B.1 Chapter 3 declaration

Declaration by the candidate:

With regard to Chapter 3 (page 27 - 35), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
The candidate jointly conceptualised and designed the research with the co-author as supervisor for the co-author's masters degree. The candidate provided input and guidance during the literature review and writing of the article. The candidate provided comments on the first draft of the article. The candidate also presented the research at the GCSM conference, in the absence of the co-author.	25%

The following co-authors have contributed to the article presented in the rest of Chapter 3 (page 27 - 35):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Johan du Plessis	jaduplessis88@gmail.com	Jointly conceived and designed the investigation with the candidate. Performed the literature review and designed the framework. Wrote the first draft of the article. Jointly edited and finalised the article.	75%

Date and signature of candidate: Declaration with signature in possession of candidate and supervisor.

Declaration by co-authors:

The undersigned hereby confirm that

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to Chapter 3 (page 27 - 35),
2. no other authors contributed to Chapter 3 (page 27 - 35) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in Chapter 3 (page 27 - 35) of this dissertation.

Name	Signature	Institutional affiliation	Date
Johan du Plessis	Declaration with signature in possession of candidate and supervisor.	Stellenbosch University	15/05/2019

B.2 Chapter 4 declaration

Declaration by the candidate:

With regard to Chapter 4 (page 38 - 68), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
<p>The candidate jointly conceived and designed the research with the co-author as supervisor for the co-author's masters degree. The candidate provided input and guidance throughout the literature review, design and testing of the framework and the writing of the first draft of the article. The candidate provided comments on the first draft of the article and actively assisted in the review process by finalising the comments to the reviewers and making updates to the document accordingly. The candidate also suggested a change in the emphasis of the article from what the focus was in the initial master's thesis</p>	25%

The following co-authors have contributed to the article presented in the rest of Chapter 4 (page 38 - 68):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Johan du Plessis	jaduplessis88@gmail.com	Jointly conceived and designed the investigation with the candidate. Performed the literature review, design and testing of the framework and the writing of the first draft of the article. Jointly edited and finalised the article.	75%

Date and signature of candidate: Declaration with signature in possession of candidate and supervisor.

Declaration by co-authors:

The undersigned hereby confirm that

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to Chapter 4 (page 38 - 68),
2. no other authors contributed to Chapter 4 (page 38 - 68) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in Chapter 4 (page 38 - 68) of this dissertation.

Name	Signature	Institutional affiliation	Date
Johan du Plessis	Declaration with signature in possession of candidate and supervisor.	Stellenbosch University	15/05/2019

B.3 Chapter 5 declaration

Declaration by the candidate:

With regard to Chapter 5 (page 71 - 106), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
The candidate jointly conceived and designed the research with the co-author (who was one of the promoters for this research). The candidate performed the literature review and the design and implementation of the framework. The candidate jointly wrote the article with the co-author. The candidate jointly edited and finalised the article with the co-author.	70 %

The following co-authors have contributed to the article presented in the rest of Chapter 5 (page 71 - 106):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Karolien De Bruyne	karolien.-debruyne-@kuleuven.be	The co-author jointly conceived and designed the research with the candidate as co-promotor for the candidate's research. The co-author provided input and guidance throughout the literature review, design and implementation of the framework. The co-author jointly wrote and edited the article.	30%

Date and signature of candidate: Declaration with signature in possession of candidate and supervisor.

Declaration by co-authors:

The undersigned hereby confirm that

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to Chapter 5 (page 71 - 106),
2. no other authors contributed to Chapter 5 (page 71 - 106) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in Chapter 5 (page 71 - 106) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Karolien De Bruyne	Declaration with signature in possession of candidate and supervisor.	KU Leuven	24/06/2019

B.4 Chapter 6 declaration

Declaration by the candidate:

With regard to Chapter 6 (page 110 - 114), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
The candidate jointly conceived and designed the research with the co-author (who was one of the promoters for this research). The candidate performed the literature review and developed the initial argument for the paper. The candidate jointly wrote the article with the co-author. The candidate jointly edited and finalised the article with the co-author.	70 %

The following co-authors have contributed to the article presented in the rest of Chapter 6 (page 110 - 114):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Karolien De Bruyne	karolien.-debruyne-@kuleuven.be	The co-author jointly conceived and designed the research with the candidate as co-promotor for the candidate's research. The co-author provided input and guidance throughout the writing of the first draft of the article. The co-author jointly edited and finalised the article.	30%

Date and signature of candidate: Declaration with signature in possession of candidate and supervisor.

Declaration by co-authors:

The undersigned hereby confirm that

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to Chapter 6 (page 110 - 114),
2. no other authors contributed to Chapter 6 (page 110 - 114) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in Chapter 6 (page 110 - 114) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Karolien De Bruyne	Declaration with signature in possession of candidate and supervisor.	KU Leuven	24/06/2019

B.5 Chapter 7 declaration

Declaration by the candidate:

With regard to Chapter 7 (page 117 - 157), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
The candidate jointly conceived and designed the research with the co-authors (who were two of the promoters for this research). The candidate performed the literature review and developed the initial argument for the paper. The candidate jointly wrote the first draft of the article. The candidate jointly edited and finalised the article with the co-authors.	60 %

The following co-authors have contributed to the article presented in the rest of Chapter 7 (page 117 - 157):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Karolien De Bruyne	karolien.-debruyne-@kuleuven.be	The co-author jointly conceived and designed the research with the candidate as co-promotor for the candidate's research. The co-author provided input and guidance throughout the writing of the first draft of the article. The co-author jointly edited and finalised the article.	30%
Prof Corne Schutte	corne@sun.ac.za	As promotor for the research, provided comments on designing structured review and for improving first draft before submission.	10%

Date and signature of candidate: Declaration with signature in possession of candidate and supervisor.

Declaration by co-authors:

The undersigned hereby confirm that

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to Chapter 6 (page 110 - 114),
2. no other authors contributed to Chapter 6 (page 110 - 114) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in Chapter 6 (page 110 - 114) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Karolien De Bruyne	Declaration with signature in possession of candidate and supervisor.	KU Leuven	24/06/2019
Prof Corne Schutte	Declaration with signature in possession of candidate and supervisor.	Stellenbosch University	5/07/2019

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B.6 Appendix A declaration

Declaration by the candidate:

With regard to Chapter A (page 168 - 179), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
The candidate conceptualised and executed the research and wrote the first draft of the article.	85%

The following co-authors have contributed to the article presented in the rest of Chapter A (page 168 - 179):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Corne Schutte	corne@sun.ac.za	As promoter for the research, provided comments for improving first draft before submission. Presented paper at conference in absence of candidate.	15%

Date and signature of candidate: Declaration with signature in possession of candidate and supervisor.

Declaration by co-authors:

The undersigned hereby confirm that

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to Chapter A (page 168 - 179),
2. no other authors contributed to Chapter A (page 168 - 179) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in Chapter A (page 168 - 179) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Corne Schutte	Declaration with signature in possession of candidate and supervisor.	Stellenbosch University	5/07/2019