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DETERMINATION OF AN EMPLOYMENT ESTIMATOR FORMULA IN UPSTREAM INDUSTRIES DUE TO MINING TECHNOLOGY IN SOUTH AFRICA

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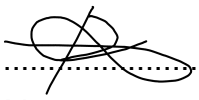
A thesis submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2021

DECLARATION

I, Paseka Johannes Katleho Leeuw, declare that this thesis is my own unaided work, except where indicated and acknowledged. It is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.



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ABSTRACT

Mining has had a positive contribution in the economy of South Africa for over 150 years through rents, income terms of trade, capital formation and employment. Since historically the mining industry in South Africa is considered as backbone of the country's economy, or a base industry of the country's economy, this thesis sought to develop an employment estimator formula to estimate employment opportunities induced in upstream industries to the mining industry in South Africa, in particular mining production backward linkage envelope, as the results of demand for input goods and services.

To achieve this objective, data from the Mining Qualifications Authority (MQA), LinkedIn, mining magazines and company websites with respect to the number of employees per major groups of occupations, locations of companies supplying mines with goods and services, countries of origin of these companies and goods and services they provide were collected. In this research, goods and services are used as proxies of technologies and companies are taken as the embodiment of such technologies. The data collected consisted of 123 companies and 13 company types, with employee data divided into eight major groups of occupations and mining input goods and services divided into 12 nodes of technology.

The analysis of data showed that South African companies had significant or dominant presence in 11 of the 12 nodes. This led to the conclusion that the consumption of locally manufactured goods and services by mines in South Africa is significant enough to support the creation of employment opportunities in the local upstream industries to the mining industry.

This paved way to the derivation of the employment estimator formula. While the thesis set out to estimate the induced employment opportunities due to consumption of goods and services (input technology), it was later determined that providers of goods work predominately off mine site and therefore it was uncertain that employment therein (including services they provide) is directly induced by the establishment of a specific mine. On the other hand, the data showed that the mining related services such as contract mining and engineering services take place on a specific mine site and therefore there is a high certainty that employment therein is induced directly by a specific mine. To this effect, the derivation of the employment estimator formula (four equations) was confined to data related to mining contractor and engineering services company types.

One deterministic and three stochastic equations were derived, with stochastic equations further divided into normal stochastic and time-dependent stochastic. The latter was further divided into two equations, i.e., one that deals with the high rate of automation of tasks and the other that deals with the low rate of automation of task due to incorporation of fourth industrial revolution (4IR) technologies into work routines. While all equations have very strong correlations with mine data used for validation, it was determined that stochastic equations provide realistic estimation of induced employment opportunities.

Notwithstanding the above, the employment estimator formulae derived in this thesis are applicable only to mining contractors and engineering services companies. In this regard, it is recommended that further work must be done to extend their application beyond aforementioned company types. It is also recommended that the methodology used in this thesis be applied in deriving other versions of employment estimator formulae at different nodes along the mineral value chains.

Keywords:

Employment estimator formula, employment opportunity, backward linkages, mining technology, mining goods and services, mining industry.

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Thank you.

PAPER ALREADY PUBLISHED FROM THESIS

The following papers have already been published out of this thesis:

Leeuw, P., Mtegha, H., 2016. The nature of mining input technology in South Africa. Journal of the Southern African Institute of Mining and Metallurgy. Volume 116, Pages 1057–1063. https://doi.org/10.17159/2411-9717/2016/v116n11a8

Leeuw, P., Mtegha, H., 2018. The significance of mining backward and forward linkages in reskilling redundant mine workers in South Africa. Resources Policy. Volume 56, Pages 31-37. https://doi.org/10.1016/j.resourpol.2018.02.004

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DEFINITIONS

Employment opportunities	Probable jobs that could be created.
Goods	Artefacts and systems traded on commercial basis.
Mining production backward linkage envelope	A sector concerned with provision of input goods and services that are consumed in mining production activities namely rock-breaking, rock engineering, mine ventilation, mine transportation (handling of personnel, material, broken rock, and pumping) and support services such as mine planning, engineering geology, mine survey, and equipment maintenance. This demarcation is important as mining is generally taken to collectively refer to activities involved in exploration; development and production (or simply production); and screening, washing, classifying, concentrating and recovery (or simply recovery).
Mining production supplier companies	Supplier companies operating within the mining production backward linkage envelope. Basically, this is a subset of mining supplier companies and in a case where a company that operates in different sectors, this will refer to divisions operating within the mining production backward linkage envelope.
Mining technology	Technology used by mining production supplier companies to design, develop and trade goods and services.
Services	Procedures, trade secrets and solutions traded on commercial basis.
Technology	Architecture within goods and/or services. Inherent in services is knowledge, skills, and attributes to perform a specific task.

ABBREVIATIONS

4IR	Fourth Industrial Revolution
ANZSCO	Australian and New Zealand Standard Classification of Occupations
ADT	Articulated dump trucks
CEO	Chief Executive Officer
CSS	Closed Source Software
DHET	Department of Higher Education and Training
DoL	Department of Labour
DPA	Directly Productive Activities
EPCM	Engineering, Procurement, and Construction Management
EU	European Union
FDI	Foreign Direct Investment
GDP	Gross domestic product
HRD	Human Resource Development
ICT	Information and Communications Technology
ILO	International Labour Organization
ISCO	International Standard Classification of Occupations
LHD	Load and haul dumper
LKAB	Luossavaara-Kiirunavaara Aktiebolag
MEC	Mineral-energy Complex
METS	Mining Equipment, Technology and Services
NQF	National Qualifications Framework
NSDS	National Skills Development Strategy
NSF	National Skills Fund
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OFO	Organising Framework for Occupations

OSS	Open Source Software
PDA	Personal Digital Assistant
PGM	Platinum Group Metal
PPP	Public Private Partnership
R&D	Research and Development
SASCO	South African Standard Classification of Occupations
SDI	Spatial Development Initiatives
SETA	Sector Education and Training Authority
SIC	Standard Industrial Classification
SOC	Social Overhead Capital
TVET	Technical and Vocational Education and Training
UG	Underground
USA	United States of America

UNITS & SYMBOLS

Aus$	Australian dollar
Mtpa	Million tonnes per annum
t	Metric tonne (1 000 kg)
US$	United States of America dollar
R	Rand (South African currency)

1. Thesis overview

1.1. Introduction

It can arguably be stated that the modern history of mining in South Africa started in 1867 with the discovery of a 21.25 carats diamond called Eureka near Hopetown in the Northern Cape. Shortly after the discovery of Eureka, diamond pipes were discovered in Kimberley in 1870. In 1886, the gold bearing reef of the Witwatersrand Basin was discovered on Langlaagte farm (Mineral Economics Directorate, 2007 and Minerals Council South Africa, 2020). The discovery of diamond pipes and gold bearing reefs made South Africa one of the most important mining jurisdictions in the world in the late 19th century and early 20th century (Leeuw, 2012).

It is then not surprising that mining is playing a significant role in the South African economy. For example, in the years from 2008 to 2018, the total mineral sales amounted to R4.13 trillion in nominal terms. In the same period, mining's average contribution to the gross domestic product (GDP) was 7.8%; primary mineral exports accounted for 30.6% of the total South African exports; and average mining gross fixed capital formation (fixed investment) was 5.9% against 4.9% of the total South African gross fixed capital formation (Minerals Council South Africa, 2019a).

In 2019, the South African mining industry directly employed 454 861 people (Minerals Council South Africa, 2020). However, this thesis seeks to primarily develop a mathematical expression to estimate employment opportunities created by mining outside mines in South Africa, in particular within a narrowly defined sector called mining production backward linkage envelope (see Definitions on page xvii).

In 2013, the South African mining industry spent R214.1 billion (43.2% of the total expenditure) on goods and services (Statistics South Africa, 2014a). The R214.1 billion spent on goods and services is significant and therefore it becomes imperative to understand how such expenditure is benefiting the South African economy. The view taken in this thesis is that goods and services flowing into mines are driven by human resource capital. This being the case, then mining expenditure becomes an employment inducement factor.

It is for this reason that this thesis primarily intends to derive an employment estimator formula to estimate employment opportunities induced in upstream industries to the mining industry in South Africa, in particular the mining production backward linkage envelope, as the results of demand for input goods and services. Employment opportunity in the context of this thesis is different from actual employment created in the sense that the former determines what is probable while the latter is constrained by economic, financial, political and social factors among others.

The employment estimator formula is important for South Africa mainly due to the fear of loss of employment due to technologies associated with the 4th Industrial Revolution (4IR), which is sometimes called Mining 4.0 in the mining industry. This fear is valid given that the official unemployment rate in South Africa in the fourth quarter of 2019 was 29.1% and rose to 32.6% in the first quarter of 2021 (Statistics South Africa, 2021). It is for this reason that it is important to establish employment opportunities that may rise due to mining procurement, and in the context of this thesis, it is employment opportunities in the mining production backward linkage envelope in South Africa.

For this purpose, it will be necessary to create a common understanding of what technology is in the context of this thesis. It will also be imperative to unpack resource

linkage theory to show where backward linkages fit in the matrix of resource linkages. It will be shown later in the thesis that the understanding of what mining technology is can result in 12 nodes of mining technology, i.e., four technology types and three classes of technology.

To achieve the objectives of this thesis, it was imperative to collect data. For this purpose, data from the Mining Qualifications Authority, LinkedIn, mining magazines and internet were collected. The data collected pertained to the number of employees per major groups of occupations, locations of mining production supplier companies in South Africa, countries of origin of these companies and goods and services they provide, using products and services as proxies of mining input technologies in this case.

1.1.1. Purpose of the study

In order to intellectualise the impact of input technology in mining and related industries and subsequent analysis thereof, it was pertinent in this research to divide mining technology into four types namely artefact and chemicals technology, machine technology, hardware and software technology, and mining related services technology. Each category is divided into three classes, resulting in twelve nodes of mining input technologies. Because technology is embedded in the architecture of goods and services, they will therefore be used as proxies of technology.

Goods and services consumed in the various pursuits of mining engineering, namely rock-breaking, rock engineering, mine ventilation, mine transportation (handling of personnel, material, broken rock and pumping) and technical support services such as mine planning, engineering geology, mine survey and equipment maintenance were

considered central to this thesis. However, goods and services consumed in supporting fields such as exploration geology, human resources, procurement, finance and downstream fields that include metallurgy and marketing were disregarded. The focus area of this research is shown in Figure 1-1.

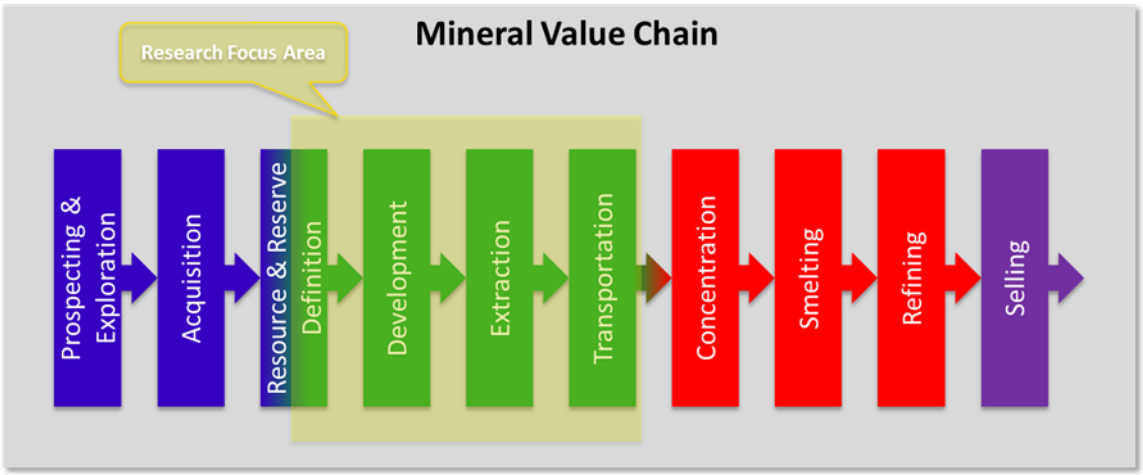


Figure 1-1: Research focus area as viewed along the mineral value chain.

The purpose of this research is therefore to derive an employment estimator formula to estimate employment opportunities induced in upstream industries to the mining industry in South Africa as the results of demand for input goods and services. Specifically, the upstream industry referred to is the mining production backward linkage envelope as defined above. It should be noted that nowhere else this definition exists except in this thesis.

Resource exploitation (including mining) results in economic linkages as discussed in Section 2.3 of this thesis. There are generally five domains of economic linkages namely production, consumption, fiscal, spatial, and lateral migration linkages. Notwithstanding the importance of all five domains, this study will place emphasis on a component of production linkage, namely backward linkage.

The envisaged employment estimator formula will enable researchers, engineers and policy makers to estimate potential employment opportunities that can be induced by the establishment, expansion, down scaling or closure of a mine.

It is hereby noted that forward linkage is the main focus area of the South African government through the South African Beneficiation Strategy and it refers to activities that add value to a mineral from a mine up to a final product purchased by the end consumer. In the forward linkage, it is generally expected that the value per unit mass of a mined product will increase along the value chain. In South Africa, the forward linkage in the mining industry is generally referred to as mineral beneficiation and is divided into four stages. These stages are defined in Chapter 1 (Definitions) of the Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) as follows:

"a) primary stage, which includes any process of the winning, recovering, extracting, concentrating, refining, calcining, classifying, crushing, screening, washing, reduction, smelting or gasification thereof;

b) secondary stage, which includes any action of converting a concentrate or mineral resource into an intermediate product;

c) tertiary stage, which includes any action of further converting that product into a refined product suitable for purchase by minerals-based industries and enterprises; and

d) final stage, which is the action of producing properly processed, cut, polished or manufactured products or articles from minerals accepted in the industry and

traded as fully and finally processed or manufactured and value-added products or articles."

Table 1-1 shows the beneficiation stages as articulated above with respect to metals and industrial minerals. In addition, economic activity associated with each mineral beneficiation stage is shown. Ideally, all mining countries should follow these stages in order to derive maximum benefit from their mineral endowment.

Table 1-1: Mineral beneficiation stages in South Africa.

Stages of Beneficiation	Metals	Industrial Minerals	Economic Sector
Primary	Saleable smelted products (*e.g. copper cathode*)	Processed raw material (*e.g. granite blocks*)	Mining
Secondary	Fabricated alloys and metals (*e.g. copper tubes*)	Basic final products (*e.g. granite slabs*)	Heavy engineering
Tertiary	Semi-manufactured articles (*e.g. armatures*)	Refined products (*e.g. polished granite tops*)	Light engineering
Final	Fabricated articles (*e.g. electric motors*)	Fabricated articles (*e.g. granite workstations*)	Retailing

Adapted from Robinson and von Below (1990)

1.1.2. The perspective of technology for the purpose of this thesis

According to Macdonald (1985) technology can be embodied within a machine or outside a machine. The example of the former would be a motor car and that of the latter would be the crop rotation technology first practiced in Europe during the 18th century. Macdonald (1985, p. 42) further stated that technology is "simply the way things are done" or simply the way of life. For example, the way we make coffee in the morning or how we consume news throughout the day has been changing over the years as our way of life changes due to technology.

Mitcham (1994) on the other hand stated that technology has both narrow and broad perspectives. The narrow perspective is associated with machines and artefacts and

is generally the perspective adopted by engineers in developing various technologies for everyday application. The broad perspective goes beyond the narrow perspective to include what people do as they interact with technology (social system). The broad perspective of technology is the social scientists' view of technology and is closely linked with the development history of the human race.

According to Lowe (1995), the narrow perspective of technology is a branch of human knowledge which applies scientific principles and practical knowledge to physical entities and systems. In this respect, Lowe gave a practical definition of technology for engineering applications in so far as goods are concerned. To this effect, technology in the case of this thesis is defined under Definitions (page xvii). Similarly, mining technology and related goods and services are defined under Definitions.

1.1.3. Types of mining technology

In order to be able to understand the type and nature of input technology into the South African mining industry that has the potential to create jobs in the mining production backward linkage envelope, mining technology was divided into four types, namely artefacts and chemicals, machine, hardware and software, and mining related services technologies. The nature of these technologies is discussed in the next sub-sections 1.1.3.1 to 1.1.3.4.

1.1.3.1. Artefacts and chemicals technology

The artefacts and chemicals technology are manufactured goods and can be described as the technology associated with the application and performance of individual pieces of artefacts that are either used in isolation or collectively to achieve

mining objectives, as well as chemicals used in mining activities. It is divided into three classes of technologies, namely single artefacts, complex artefacts, and chemicals. In some cases, artefacts can be combined to produce new artefacts or units provided they are not classified as a machine. For example, a nut, plate, and rebar (single artefacts) can be combined to produce a roofbolt, which in this case will be a complex artefact.

Single artefacts are goods primarily produced to perform a single function, e.g. a nut is used to tighten a bolt[1]. Complex artefacts are goods with complex design structures or a combination of single artefacts. For example, X-Pandabolts (roofbolts) are a combination of single artefacts as described above with capability to indicate to the operator whether they have been installed properly or otherwise. Lastly, chemicals technology are chemicals used in tasks associated with mining such as resin used to increase effectiveness of roofbolts or explosives used in blasting activities.

1.1.3.2. Machine technology

Machine technology can be described as the technology that replaces or enhances muscular effort in doing work. It is divided into three classes, namely manual, automatic, and autonomous technologies. Manual technology is the one that requires constant human interaction for the machine to function; automatic technology is the one that executes certain functions automatically without human intervention, but the human retains overall supervision; and autonomous technology is the one that allows machines to make decisions without human involvement.

[1] Other uses, outside what the manufacturer has prescribed, may be engineered in the field.

The evolution of machine technology from manual to autonomous operations was outlined by authors like Sheridan (1992) and Roberts et al. (2002). Table 1-2 is an adaptation of the work of Sheridan (1992; p. 358) and it shows the evolution of machine technology from non-computational processing with high level operator interaction to a high level of computational processing without any operator required. Figure 1-2 is an adaptation of a machine technology evolution model by Roberts et al. (2002, p. 136) where the information in Table 1-2 has been superimposed. As indicated in Figure 1-2, the differences in the classes of machine technology in mining application is the mode of control of the underlying vehicle or machine.

Table 1-2: Levels of automation under machine technology type, adapted from Sheridan (1992, p. 358).

Level of Automation	Description
1	A machine offers no assistance; the operator must do it all.
2	A machine offers a complete set of solutions and the operator must choose the optimal solution; no further action until a selection is made.
3	A machine narrows solutions down to few options and the operator must choose the optimal solution; no further action until a selection is made.
4	A machine suggests an optimal solution and the operator must ignore, approve, or reject the solution; no further action until a selection is made.
5	A machine suggests an optimal solution and gives the operator a limited time to ignore, approve, or reject the solution; if there is no response within a given time the machine discretionally executes the solution.
6	A machine executes the optimal solution automatically, and then informs the operator when necessary.
7	A machine executes the optimal solution automatically and informs the operator only when asked.
8	A machine makes human-like decisions and acts autonomously.

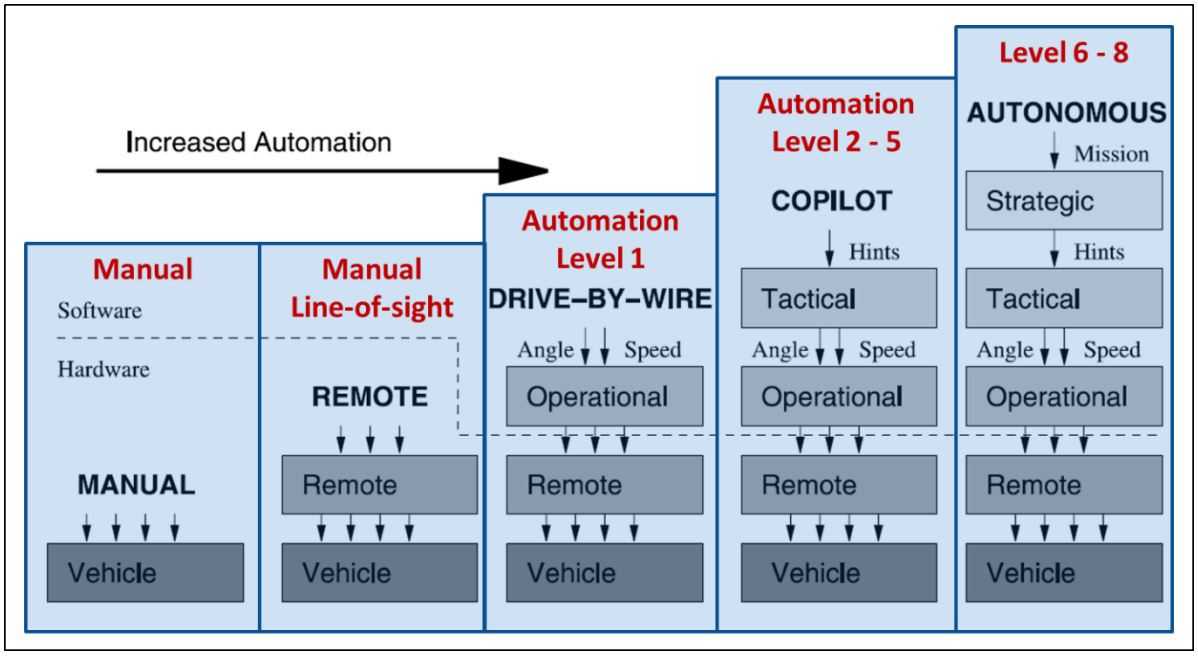


Figure 1-2: Evolution of machine technology, adapted from Roberts et al. (2002, p. 136).

1.1.3.3. Hardware & software technology

Hardware and software are modern terms associated with technology. Hardware refers to tangible electrical or electronic objects that use instructions in a coded form to execute tasks and software refers to a set of intangible computer programmes that are developed to analyse and manipulate data. There are three basic types of software in the information technology space, namely application software, system software (operating system), and malware (virus) and the focus of this thesis is on the application software. The system software is generally embedded in the hardware (computers and personal digital assistant (PDA) devices) and for the purpose of this thesis will be considered as part of the hardware, while malware is undesirable software often developed to cause harm or system malfunction. The application software can be divided into open source software (OSS) and closed source software

(CSS) (von Engelhardt, 2008). The focus will be on the latter as it is traded commercially.

For the purpose of analysis, the application software technology was divided into two classes, namely, monitoring and control software, and planning and design software. The focus in these two classes was on specialised mining applications (vertical units) and not on general applications (horizontal units) such as word processors and spreadsheets.

1.1.3.4. Mining related services technology

Mining related services technology refers to services that are offered by specialists in the fields of mechanical, electrical and mining engineering as discussed in Section 1.1.1. Mining related services technology were divided into three classes namely engineering services, mining services and mining engineering services technologies.

The engineering services deals with mining related services within the broad ambit of mechanical and electrical engineering disciplines, for example mechanical repairs or physical installations. The mining services deals with mining related services within the ambit of the mining engineering discipline, which do not necessarily require the services of a mining engineer, for example haul road maintenance. The mining engineering services deals with mining related services within the ambit of the mining engineering discipline, which are exclusively provided by mining engineers.

It is also acknowledged that there will be elements of side-stream linkages[2] among the firms that provide mining related services to the mines. This means that where side-

[2] See Section 2.3.1.3 for discussion on side-stream linkages.

stream linkages exist, service firms source their inputs from the same companies that mines source their inputs from and use these inputs to provide solutions to the mines in a similar fashion the mine would have done should they have opted for in-house solutions. For example, a mining contractor might purchase machinery and application software from the same suppliers that supply their client (a mine). In this instance, the service and not the good was considered in so far as the good is not transferred to the mine.

1.2. Research motivation

South Africa is well known for its mineral endowment, particularly chrome, gold, manganese, and platinum group metals (PGMs) resources. In 2018, it was ranked first globally in reserves of chromium, manganese, PGMs; second globally in reserves of zirconium; and third in reserves of gold (Minerals Council South Africa, 2019a).

Informed by the knowledge of its mineral endowment, South Africa in 2010 developed a strategy to beneficiate 14 of its minerals as shown in Table 1-3. The main thrust of the strategy is to derive more value from the locally mined minerals and create employment in the process.

Table 1-3: Mineral value chains in the South African Beneficiation Strategy document (Department of Mineral Resources, 2011).

Downstream Industry	Minerals
Energy	• Coal • Uranium • Thorium
Iron and Steel	• Iron ore • Chrome • Manganese • Nickel • Vanadium • Coal
Pigment and Titanium metal	• Titanium
Autocatalytic converters and Diesel particulate filters	• PGMs
Jewellery	• Gold • PGMs • Diamond

The South African mining industry has a significant contribution in the country's economy. In 2013, mining and quarries (mining industry) in South Africa contributed 6.7% to the total turnover of all the sectors in South Africa (Statistics South Africa, 2014a). It can be observed in Figure 1-3 that the mining sector was the fifth largest contributor to the 2013 total South African turnover out of the nine economic sectors when government departments were excluded.

Furthermore, in 2013, the South African mining industry accounted for 19.4% and 12.2% of the total private sector investment and total investment in the South African economy, respectively. It also accounted for 30.5% of the total exports of goods and commodities in the same year (Chamber of Mines of South Africa, 2014). When the total impact of mining or its multipliers were taken into account in 2013, the contribution of mining to the South African economy increased from 6.7% to 17%. The multiplier effects of mining in the South African economy come mainly in the form of social development, primary income, employment outside mining industry, income terms of trade, and capital formation as explained in Table 1-4.

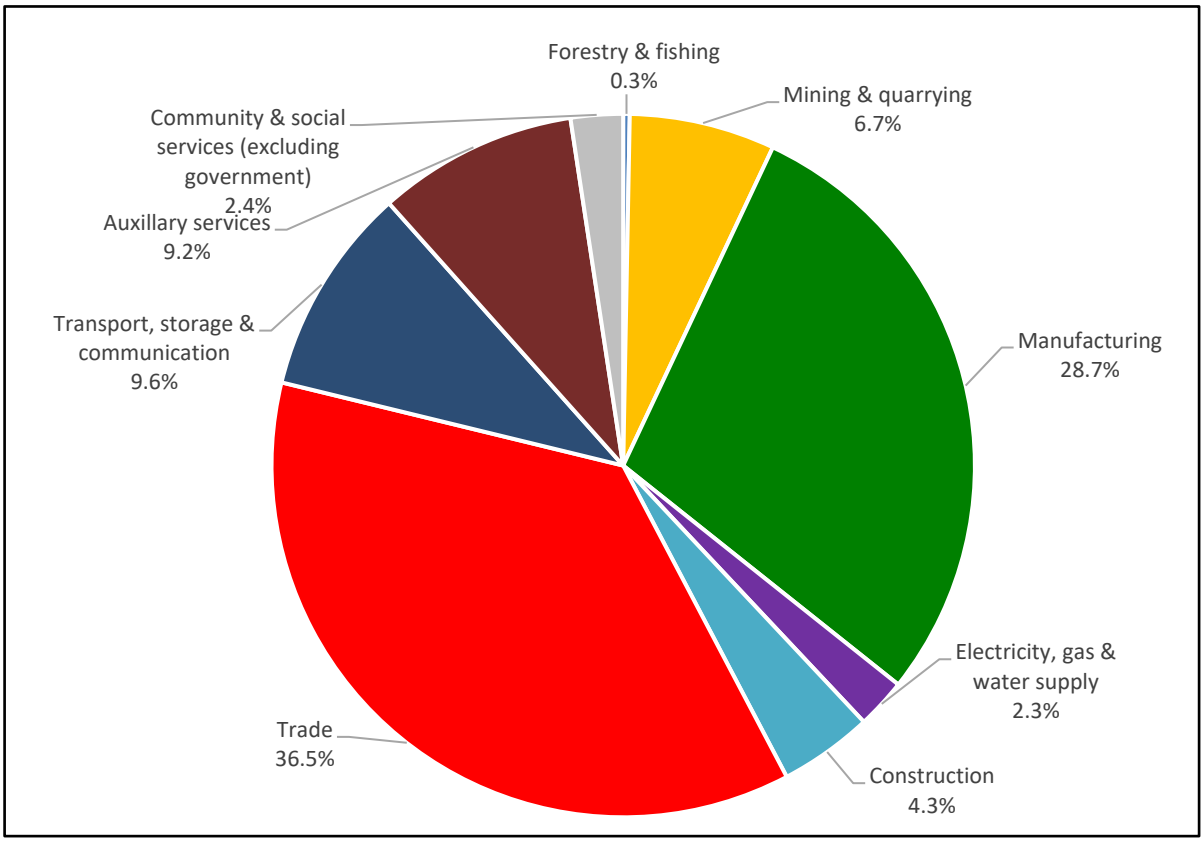


Figure 1-3: Percentage contribution per economic sector to the total 2013 turnover in South Africa (Statistics South Africa, 2014a).

Table 1-4: Typical mining multipliers in South Africa (Jones & Baxter, 2002, pp.83–84).

Multiplier	Description
Social	Construction of infrastructure by mining companies such as housing, roads, schools and clinics, and provision of utilities such as electricity and recreational facilities.
Primary incomes	Household demand for goods as the consequence of primary income derived from the mining industry.
Employment	Jobs created in other industries due to demand or supply of goods (and services) by the mining industry.
Income terms-of-trade	Net positive effect on the balance of payments, foreign currency reserves, monetary policy, and general business confidence induced by mining exports.
Capital formation	Positive effect by the mining industry in attracting inflow of foreign capital and generating domestic capital as well.

The South African mining industry's turnover in 2013 was R469.8 billion (R524.5 billion when investments, trademarks and other sources were taken into account) against a total expenditure of R495.2 billion. The expenditure as shown in Figure 1-4 included R214.1 billion (43.2%) in purchases of goods and services, R106.7 billion (21.5%) in salaries and wages, R63.8 billion (12.9%) loss in financial instruments, R23.5 billion (4.8%) on rental and leasing of land, plant and machinery. The company tax paid was R9.3 billion and dividends provision was R18.1 billion (Statistics South Africa, 2014a).

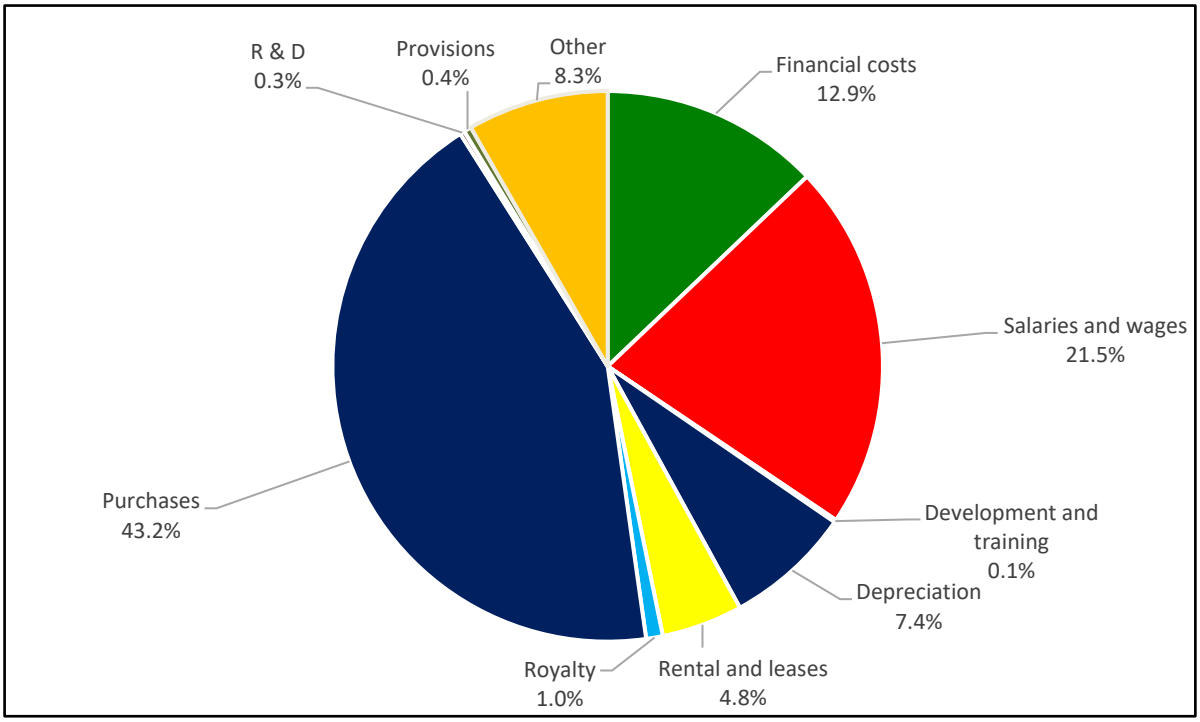


Figure 1-4: The breakdown of the South African mining industry expenditure in 2013 (Statistics South Africa, 2014a).

Of importance in the context of this study, is the annual purchases of goods and services by the South African mining industry, as this is the value of the productive backward linkage into the economy. The downside, based on the postulation of Lombard (1980) and Tregenna (2007), is that the import component of the South African mining industry procurement value is significant, resulting in the local economy not fully benefiting from the industry's expenditure. The implication is that the local

manufacturing capabilities and provision of services, as far as the mining inputs are concerned, can be significantly undermined when the import component of goods and services going into local mines is high.

The capacity to manufacture mining inputs or provide services is inextricably linked to the domestic backward and side-stream linkages in the short to medium term and lateral migration in the long term. Growth in these linkages will invariably result in the creation of local job opportunities. Figure 1-5 shows an inherent job creation potential in backward linkage industries as it can be observed that there has been a growing trend in the annual expenditure of the South African mining industry in current terms from 2003 to 2013.

It can also be observed in Figure 1-4 and Figure 1-5 that purchases and salaries and wages accounted for a bigger portion of the expenditure over a period of 10 years. The potential economic benefits and job creation potential of the former, going forward insofar as purchases of goods and services, are enormous provided a large portion thereof is spent locally. According to Table 1-4, purchases are related to the creation of employment in backward linkages.

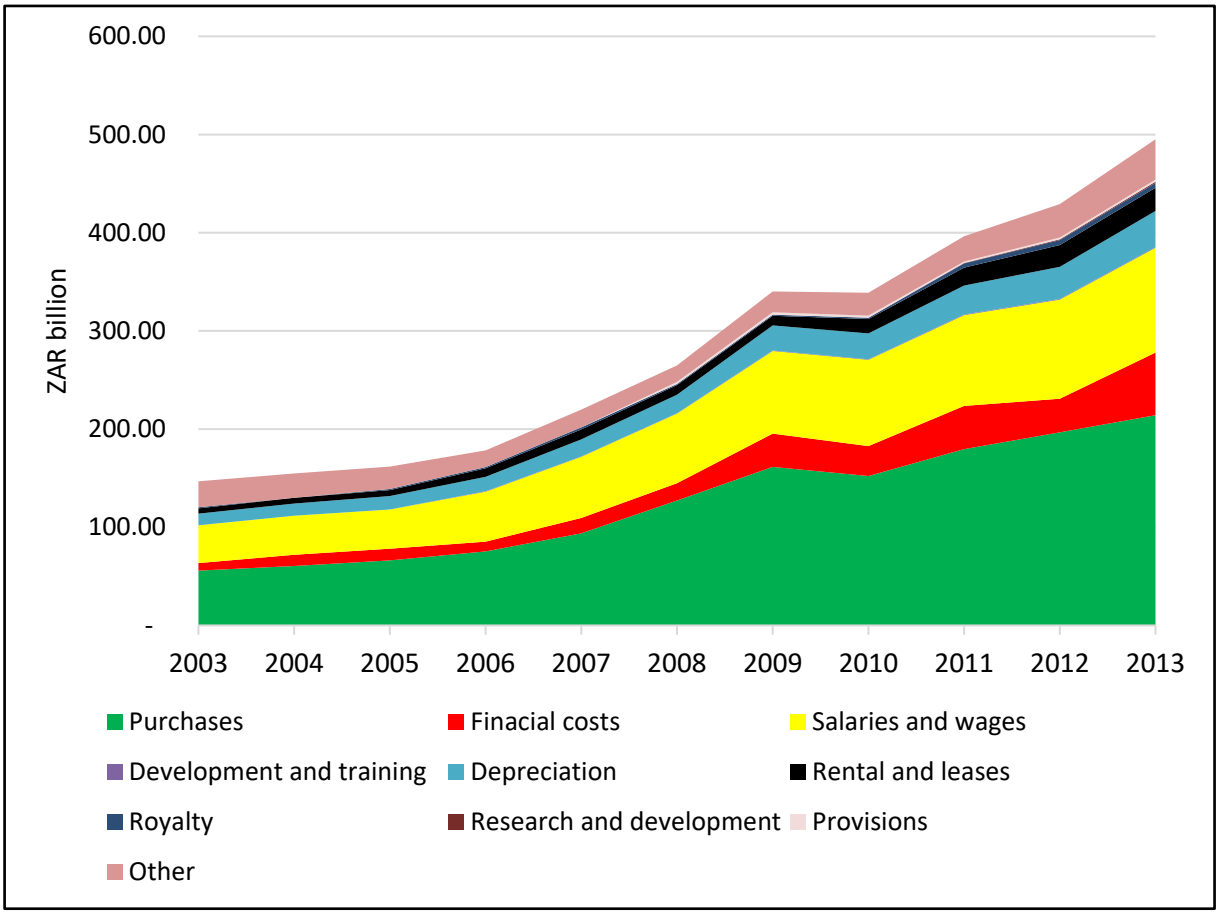


Figure 1-5: An expenditure trend of the South African mining industry from 2003 to 2013 (Statistics South Africa, 2014a).

In the study commissioned by the Chamber of Mines of South Africa (now Minerals Council of South Africa) in 2000, it was stated that "South Africa has used its mining activities as a base to nurture a cluster of highly competitive mining and mineral processing-related goods and services industries, supporting both local and international markets" (Walker & Jourdan, 2003: p. 36). The implication of this statement is that the impact of import component of mining inputs alluded above is minimised to some extent and the prospect of creating employment in mining production supplier companies is enhanced.

If the concept of mine modernisation in South Africa is taken into account, there is a high likelihood that the import component in mining capital goods can be kept low. The

concept of mine modernisation is largely about mechanising conventional labour-intensive narrow reef mining. To be successful, mine modernisation "needs to be addressed in a holistic manner, adopting a systems and people-centric approach. All elements of mining – including reporting structures, skills development, change management, stakeholder engagement, community development and environmental management – need to be modernised" (Minerals Council South Africa, 2019b; p. 2).

Furthermore, Minerals Council South Africa (2019b) is of the view that mine modernisation has the potential to save 200 000 mining jobs by 2030 and thereby affecting 2 million dependents. The view in this thesis is that if mine modernisation is localised, that is, if resultant equipment are manufactured locally (including services), just this concept alone will result in significant number of jobs outside the mining industry.

Notwithstanding the above and despite its mineral endowment, South Africa has a chronic unemployment problem and high levels of inequality and poverty (National Planning Commission, 2011). In the fourth quarter of 2012, the South African official unemployment rate stood at 24.9% (4.5 million people) and improved marginally to 24.1% (4.83 million people[3]) in the fourth quarter of 2013. The total number of people not active in the economy (including the unemployed) was 15 million and 15.01 million, while those economically active were 18.1 million and 20 million, respectively in the fourth quarters of 2012 and 2013 (Statistics South Africa, 2013; and Statistics South Africa, 2014b). In the first quarter of 2021, the official unemployment rate increased to

[3] The increase from 4.5 million to 4.83 million was partly due to new entrants in the job market at the beginning of first quarter of 2013.

32.6% while the youth unemployment (15-34) was 46.3% and graduate unemployment was 9.3% (Statistics South Africa, 2021).

Interestingly, the number of employed South Africans dropped from 20 million in 2013 to 15 million in 2021 despite having national strategic plans such as those outlined in the South African Beneficiation Strategy (Department of Mineral Resources, 2011). According to the Department of Mineral Resources, 2011), South Africa had a target of creating five million jobs through various initiatives including mineral beneficiation by 2020.

In South Africa, inequality correlates well with lack of salary or wage income as opposed to the United States of America (USA) where, for example, inequality is driven by more people (mostly women) settling for a minimum wage and consequently driving the price of labour downwards, growth in price index, difference in the life expectancy between the rich and the poor, as well as the rich (e.g. CEO) cornering a large percentage of the national income (Leibbrandt et al., 2010; and Belsie, n.d.).

Given the South African mineral endowment and the poor general understanding of its social benefits, it is crucial to seek avenues that can demonstrate these benefits. The view taken in this thesis is that there is, among others, a latent employment linkage effect due to mining's consumption of input goods and services that must be understood. The understanding of how and where employment is created will lead to policies that enhance social and economic benefits of the South African mineral endowment.

1.3. Problem statement

Given the endowment of mineable mineral resources in South Africa; the global growth in mineral demand due to the growing middle-class population and high levels of poverty, inequality and unemployment in South Africa, it is prudent for the government to develop measures to derive more value from its mineral resources. To this effect, South African Mineral Policy and South African Beneficiation Strategy are the two examples in South Africa policy framework that are at the centre of the quantification of the mineral benefits. Associated examples of legal instruments in this regard are Mineral and Petroleum Resources Development Act 28 of 2002 which has created equitable access to mineral resources and sustainable development thereof; Mineral and Petroleum Resources Royalty Act 28 of 2008 which is imposing royalties upon transfer of mined minerals; and various forms of taxes including Income Tax Act 58 of 1962 which imposes tax on company profits.

Agencies such as Statistics South Africa in reports like D0405.2 and P2041; Mineral Council South Africa in a series of reports titled Facts and Figures; Department of Minerals & Energy in a series of reports titled South Africa's Mineral Industry; and Trade & Industry Policy Strategies in regularly published discussion documents record and publish output volumes, values of mineral sales and job statistics and to some extend communicate the benefits of mining in South Africa. However, in all the examples of the documents mentioned above, apart from the past and current statistics therein, it is difficult to estimate local jobs that will be created in companies that supply the mining industry with goods and services. It is for this reason that this thesis set out to develop the employment estimator formula. This formula can ultimately be used by mining companies and policy makers to plan and communicate the benefits of mining in so far as job creation opportunities in mining host communities are concern.

It is nonetheless conceded that the Input-Output Analysis model, in particular the employment multiplier, can be used for this purpose. However, the shortcomings of an Input-Output Analysis model is that it is generally not composed in the manner that it exclusively look at mining production supplier companies. In addition, the model cannot be used as an estimation tool over a long term, the results thereof are valid for one to three years at the most under constant technology environment, that is the model assumes that there is no change in the technology by all agents in the model (Miller and Blair, 2009). With a constant and rapid change in the technology under 4IR, there has to be a way of modelling such change when estimating employment opportunities.

1.4. Research objectives

The primary objective of this research is to develop an employment estimator formula to estimate employment in upstream industries to the mining industry in South Africa, specifically in the mining production backward linkage envelope, as the result of demand for goods and services. The secondary objective is to create an understanding of where jobs in the mining production backward linkage envelope are being created in South Africa due to mining production inputs.

1.5. Research questions

- **Research Question 1**

Mining take place largely in all provinces of South Africa and Kaplan (2011) has indicated that while the mining input cluster "is geographically fairly widely distributed much of the mining equipment industry is located on the East Rand, principally in Ekurhuleni, and largely in Farrramere *[sic]*". Similarly, Lydall (2009) found that most

firms that supply good and services to the entire value-chain of the platinum mining sub-industry are based in the Gauteng Province.

These findings showed a skewed spatial distribution of mining input suppliers, at least with respect to the entire mining value chain. However, during general visits to mines in the various provinces in South Africa, one always got the feeling that mining input suppliers, particularly those falling in the narrow scope as defined in this thesis, do creates jobs locally. Therefore, a research question arising in this respect is as follows:

Where in South Africa is the concentration of jobs related to mining production supplier companies of goods and services?

- **Research Question 2**

The world is firmly in the mist of the fourth industrial revolution or 4IR, also known as Mining 4.0 in the mining fraternity in South Africa. The 4IR is described as the disruptor technology with the potential to create redundancy in some of the current occupations while at the same time create new occupations. The research question in this regard is as follows:

Which occupations in mining production supplier companies will be affected by the incorporation of 4IR technologies in tasks performed?

- **Research Question 3**

It is acknowledged that redundancy in occupations due to 4IR technologies will also take place within the mines over time as these technologies are being entrenched in various tasks in the mines. With this view, efforts to reskill redundant mine employees

must be expedited through various Sector Education and Training Authorities. The most relevant economic spaces where such employees can be absorbed after reskilling, apart from subsistence community projects, is in mining input suppliers, particularly services-oriented suppliers (Leeuw and Mtegha, 2018). The research question in this respect is:

Can the change in occupations due to the incorporation of 4IR technologies, if any, be modelled over time?

The answers to these questions may have material effect on the efforts of reskilling redundant mine employees and the distribution of mining benefits in various forms including consumption linkages as discussed in Section 2.3. For example, if job creation is concentrated in the Gauteng Province, particularly the Ekurhuleni Metropolitan, efforts to reskill[4] redundant mine employees from other provinces or even other metropolitans or municipalities in the Gauteng Province can be hampered with the need for reskilled employees to relocate. There will also be a high likelihood that Ekurhuleni Metropolitan is enjoying the biggest share of mining related consumption linkage.

1.6. Delimits of the research

Employment opportunities may not necessarily translate into actual jobs but is nonetheless an indication of what is possible. Actual jobs created depend on a number of factors including prevailing economic factors, economic outlook, policy certainty and labour market dynamics, among others. These factors are not the subject of this thesis,

[4] Reskilling in this case refer to imparting of new job skills to redundant mine employees. This may include skills that are relevant to current or future occupations in mining and/or occupations within the mining production backward linkage envelope or beyond.

but the outcome of the thesis must be interpreted while taking these factors into account.

1.7. Research method and data reliability

This thesis followed a quantitative research strategy underpinned by a positivist paradigm. This positivist epistemological approach primarily seeks to explain the relationship between variables. For this purpose, primary employment data were collected from the Mining Qualifications Authority (MQA), LinkedIn and company websites, where the MQA is deemed to be a reliable source as it is a statuary requirement for companies to submit employee related data to MQA. Data from LinkedIn and company websites was deemed to be from unreliable source. In this case, data from LinkedIn and company websites were interrelated to MQA data to improve reliability. Reliability with respect to company location and operational sites was improved by researching multiple sources such as the internet and mining magazines.

1.8. The thesis structure

This thesis consists of eight chapters. Chapter 1 introduces the research and outlines the motivation of the research, the problem statement, and research objectives among others.

Chapters 2 and 3 provide a chronological and geographical case-study analysis of the mining inputs context, with bias towards production mining inputs in order to create a foundation for the research study. In particular, Chapter 2 discussed the evolution of the resource linkage theory and associated five domains as well as international

experiences with respect to the resource linkage theory focusing mainly on the lessons learned, including successes and failures. The focus of Chapter 3 is on the South African experience with regard to the resource linkage theory.

Chapter 4 seeks to create an understanding of classes of occupation, with a bias towards occupations in the mining production backward linkage envelope. It further takes a view of the impact of the 4th Industrial Revolution on employment going forward.

Chapter 5 describes the method followed in determining sample size, sources from where information was collected and the research methodology followed. Chapter 6 provides an analysis of the information gathered mainly with respect to the secondary objective of this thesis.

Chapter 7 discusses how various formulae of employment estimator were derived and the validation thereof in line with the primary objective of this thesis. Lastly, Chapter 8 provides a conclusion of the thesis by summarising pertinent points and highlighting the new knowledge emerging from this thesis.

2. A review of resource linkage theory

2.1. Introduction

The paradigm in this thesis is that mining technology through resource linkage effects or multipliers can create more employment opportunities outside the mining industry than within. To be able to see how this is possible, it is imperative to understand the resource linkage theory.

Originally, the resource linkage theory was comprised of two dimensions namely forward and backward linkage effects. In the period from the 1950s to the early 2000s, the theory was reconfigured into five domains, namely production, consumption, fiscal, lateral migration and spatial linkages.

The origin of resource linkages as conceived by Hirschman (1958) can be traced to robust discussions that intensified after World War II on whether a balanced or unbalanced growth model is appropriate for a developing country. It is worth noting that the balanced growth model was posited in the 19th century and after World War II in the 1940s, a counter position that favoured the unbalanced growth model was put forth.

2.2. Balanced and unbalanced growth doctrines

2.2.1. Balanced growth doctrine

The two bodies of knowledge in development economics that have contributed to the resource linkage effect theory, particularly for developing countries, are balanced and unbalanced growth doctrines. The conception of the balanced growth doctrine is attributed to Friedrich List (1789-1846), a German-American economist (Clairmonte, 1959 and Streeten, 1959). Friedrich List is known for his book titled *National System of Political Economy* in which he emphasised that true economic prosperity and liberty can be achieved when a nation, rather than individuals as advocated by Adam Smith and Jean-Baptiste Say, systematically progress from the primary economic activities (e.g. agriculture and mining) to secondary economic activities (e.g. manufacturing), and ultimately to tertiary economic activities (e.g. commerce and ICT) over time (List and Colwell, 1856).

The balanced growth doctrine as influenced by List "recognizes the need for synchronized advances in terms of the mass integral mobilization of the dormant productive potentialities of the nation, both human and natural, according to a boldly conceived schedule of rational priorities" (Clairmonte, 1959: p. 24). In the balanced growth doctrine, all the important sectors of the economy can rise over time and usher a new period of economic prosperity. According to Friedrich List, national prosperity will ultimately lead to real political liberty.

The post-World War II proponents of balanced growth doctrine *inter alios* were Rosentein-Rodan (1902 – 1985), Ragnar Nurkse (1907 – 1959) and Arthur Lewis (1915 – 1991). In his version of balanced growth, Rosentein-Rodan (1943) stressed

that economically depressed regions (e.g. Eastern and South Eastern Europe at that time) could be revived through large scale investments in many industries simultaneously resulting in a 'Big Push'[5] effect. The idea of the Big Push was to create complementarities among industries within the region, which in the passage of time would result in external economies in the form of clustering of firms (Marshallian externalities) and ultimately lead to a birth of new industries. According to Rosentein-Rodan, this approach would have lowered the risk of investment and created a higher marginal social net product[6] rather than the corresponding marginal private net product[7]. The former would have enabled governments to continue growing their economies for the betterment of their citizenry.

In this regard, Rosentein-Rodan suggested the use of external sources of investments (for example foreign direct investment), in particular from developed countries rather than internal funds of developing countries, in order to minimise disruptions to domestic social programmes. The idea was that, apart from averting disruptions to local social programmes, external sources of investment would bring in expertise that the local economies lack and would accelerate the establishment of institutions geared towards economic growth, while simultaneously imparting skills to the local people.

[5] "The 'big push' would involve initiating a large number of interdependent projects simultaneously. The principal justification for such action is based on the phenomenon of external economies" (Hansen, 1965: p3).

[6] "The marginal social net product is the total net product of physical things or objective services due to the marginal increment of resources in any given use or place, no matter to whom any part of this product may accrue" (Pigou, 1932).

[7] "The marginal private net product is that part of the total net product of physical things or objective services due to the marginal increment of resources in any given use or place which accrues in the first instance - *i.e.* prior to sale - to the person responsible for investing resources there. In some conditions this is equal to, in some it is greater than, in others it is less than the marginal social net product" (Pigou, 1932).

In support of Rosentein-Rodan's views, Nurkse (1953) brought forth a balanced growth model for developing countries where simultaneous investments are made in different industries to promote and enlarge domestic consumption, akin to the growth model of Japan. Irrespective of whether the main development agent is the state or Schumpeterian entrepreneurs, the thrust of Nurkse's argument was that widespread, coordinated, and simultaneous investments undertaken in a developing country would lower economic risks that a single large investment would face. That is, if large enough investments are made in different industries simultaneously, some could fail, some may have lacklustre growth, and some may turn out to be successful, but what remains is that such investments would have resulted in overall positive marginal social net product. There will also be an opportunity for subsequent investments and repositioning of failed industries.

In the same vein, Lewis (1955) emphasised simultaneous investments in both the agriculture (agrarian) and manufacturing (industrial) sectors. This, in his view, was crucial in developing countries with a high agrarian population. The idea was that simultaneous investments would pull excess labour away from the agrarian sector into the industrial sector and thereby resulting in a larger domestic market for both industrial and agricultural produce provided the wages in both sectors were a fair compensation. In the case where compensation was fair, it was generally expected that workers in the industrial sector would earn more than workers in the agrarian sector, and thereby be placed in a better position to afford more goods comparatively.

To this effect, Lewis pointed out that during the early stages of economic growth there has to be a balance between exports and domestic consumption. The key to this balance could be achieved largely in two ways. Firstly, there has to be a critical mass

of industrial labour, which, in his view, could be achieved by mass transfer or employment of excess agrarian labour into the industrial sector. Secondly, there has to be a concerted effort to elevate the wages of those remaining in the agrarian sector through upskilling programmes.

Given that both mining and agriculture are found in the primary sector of the economy, the same arguments of Lewis can be extended to mining, in particular conventional mining methods. These are characterised by labour intensive activities and low skill sets. A move a towards technology intensive modern mining methods invariably results in the reduction of labour in a mine and the corresponding upskilling and better remunerations. Based on Lewis' arguments, there must be a corresponding labour absorption of excess or redundant mining labour into the local secondary industries and perhaps even in the tertiary industries. This absorption of excess labour, in the context of South Africa, should lead to growth in employment opportunities outside the primary sector (i.e. mining).

2.2.2. Unbalanced growth doctrine

The criticism of the balanced growth doctrine and hence the support for the unbalanced growth came from economists such as Albert Hirschman (1915 – 2012) and Paul Streeten (1917 - 2019). Hirschman (1958) pointed out that initial investment in a developing country, if successful, will create economic imbalance (for example in the form of profits, capital growth or public demands) and one way of correcting this imbalance is through subsequent investments until balance is attained. To this effect, Hirschman argued that a balanced state is an ideal state that will never be achieved under any investment regime. Subsequent investments aimed at attaining balance

generally result in economic growth and with that comes new demands. In short, investments create unbalanced growth.

This being the case, Hirschman suggested that initial investments and subsequent investments in developing countries should rather be made in ventures, which consume large inputs and create few outputs rather than the other way around. A good example of this line of thought is in mining where large and variant input resources have to be consumed to produce one or few metals or metal ores. The strategic targeting of ventures with large input consumption and few outputs during the development stage constitutes a deliberate unbalanced growth strategy that is more realistic than the idealistic balanced growth option, given that there are limited factors of production in developing countries.

Streeten (1959) agreed with Hirschman that greater leverage in developing countries can be achieved by carefully selecting projects with high marginal private and social net products. To this effect Streeten (1959: p. 183) suggested the following mechanism:

i. “while advancing some sectors, concentrate the pressure of unbalance on groups and sectors whose response to a challenge is likely to be strongest;

ii. while creating bottlenecks, also break them;

iii. while providing products and services for industry, agriculture, and consumers, also induce new development to take place in other directions, directly and indirectly related to them; and

iv. while providing a new product or service, require consequential investments in other lines".

2.2.3. Balanced and unbalanced growth doctrines in perspective

The doctrines of balanced and unbalanced growth, as mentioned above, were instrumental in the development of the resource linkage effect theory for developing countries. Both doctrines are similar in the sense that they advocate for investments that are large enough to result in positive marginal social net products, and even perhaps marginal private net products. The difference comes in the mechanism to achieve these marginal net products. The balanced growth doctrine advocates for large scale, indiscriminate and simultaneous investments in economic sectors of a developing country, whereas the unbalanced growth doctrine calls for initial targeted investments that will result in unbalanced demand and subsequent investments to balance the demand in a developing country.

2.3. The resource linkage effect theory

The resource linkage effect theory as conceived by Albert Hirschman is directly linked to the unbalanced growth doctrine and is based on the idea of interdependence between industries (Jones, 1976), underpinned by the effects of inputs and outputs on one hand and income on the other. It can be divided into five domains, namely, production, consumption, fiscal, spatial, and lateral migration linkages.

The linkage effect or connectedness between industries arises when there is a movement of goods (especially intermediary goods) or provision of services between firms in the economy. The effect is strong when the volume of goods and services and

ultimately profit margins are high and the reverse is true when volumes and profit margins are low.

According to Sutcliffe (1964), the apparent driver of connectedness between industries is the level of technology in the country. The implication being that countries with high levels of technology usage or developed countries in general tend to create better linkages between industries both locally and internationally. This connectedness gives developed countries competitive advantage over developing countries in the provision of goods and services, resulting in positive terms of trade in their favour. This situation tends to undermine linkages in developing countries and therefore perpetuate their periphery status.

Notwithstanding the above, developing countries should endeavour to understand linkages and their effects in domestic economies. This is particularly paramount to resource endowed countries. The understanding of linkages should lead to the development of appropriate resource exploitation and industrial policies geared towards migration from the periphery to the centre of global trade. To this effect, the five domains of the linkage theory are discussed below.

2.3.1. Production linkages

The main components of production linkages are forward (downstream) and backward (upstream) linkages, which were conceived by Hirschman in 1958 based on his economic observation of Latin countries in South America. The third component of the production linkage is the side-stream linkage and it is a relatively modern concept which sought to describe linkage dynamics within the backward linkage in South Africa (Walker and Jourdan, 2003; and Lydall, 2009). Hirschman (1958) was of the view that

backward linkages are more important than forward linkages at the initial stage of investments in developing countries. Perhaps the conception of the side-stream linkage in the 2000s is a testimony of the importance of backward linkages in the economy of a developing country even years after initial investments have been made.

For linkages to have a meaningful impact in developing countries, they must be important and strong. The importance of linkages refers to the combined inputs of newly established domestic industries into the base industry[8]. The higher the volume of output of companies in the secondary industry into the base industry, the higher the importance of the linkages. The strength of linkages refers to the inducement factor of new industries in the economy due to the formation of the base industry. When more secondary companies are established to supply the base industry, then the higher is the strength of the linkages of the base industry (Hirschman, 1958).

The mining industry as a base industry, has the potential to induce important and strong linkages. Since the mining industry was started over 150 years ago in South Africa, the modern mining industry in the country is generally regarded as the cornerstone of the economy with a litany of secondary companies formed due to its existence (Leeuw, 2012).

2.3.1.1. Forward linkages

According to the linkage theory, a forward linkage is a linear process of adding value to products by transferring them from the original industry into successive industries

[8] Base industry is a group of firms within the primary sector of the economy that are collectively primary source of linkage effects.

as intermediate products from which the end consumer products are produced. Under the forward linkage model, theoretically the size of the product becomes smaller with every successive industry or stage (a node along the value chain) while its value supposedly increases (see Figure 2-1).

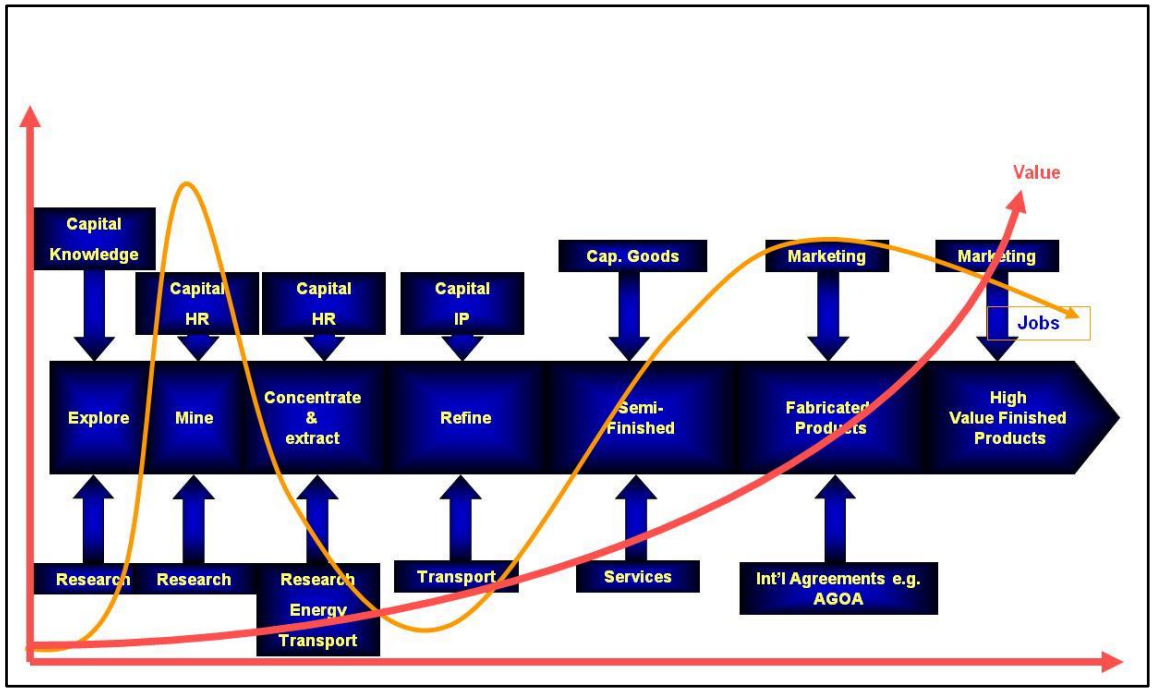


Figure 2-1: Mineral beneficiation along the value chain (Mtegha, 2009 in Leeuw, 2012).

For example in 2011, according to the Department of Mineral Resources (2012), the South African sale of 9.4 million tonnes of chromite ore was worth R8.6 billion (R913.7/t), while the sale of 3.4 million tonnes of chromium alloys was R27.2 billion (R7 780/t). Similarly, the sale of 61.7 million tonnes of iron ore in 2011 was R62.7 billion (R1 015/t), while the sale of 4.6 million tonnes of ferro-alloys was R37.8 billion (R8 200/t). In rand per tonne (R/t) terms, mineral beneficiation increased the value of chromite and iron ores by 751% and 708%, respectively.

In the South African mineral extractive sector, companies involved in forward linkages or mineral beneficiation (as it is normally called locally) are generally characterised by high capital intensity, high energy consumption and extensive use of minerals, a phenomenon referred to as the mineral-energy complex (MEC). Companies within the MEC are mines (base industry), refineries, Eskom and other heavy engineering firms (Fine & Rustomjee, 1996 and African National Congress, 2012). Figure 2-2 shows the relative position of MEC along the mineral value chain. According to Figure 2-2, job opportunities are relatively limited in the early phases of mineral beneficiation or within the MEC compared to later phases comprising mostly of light engineering firms (manufacturing).

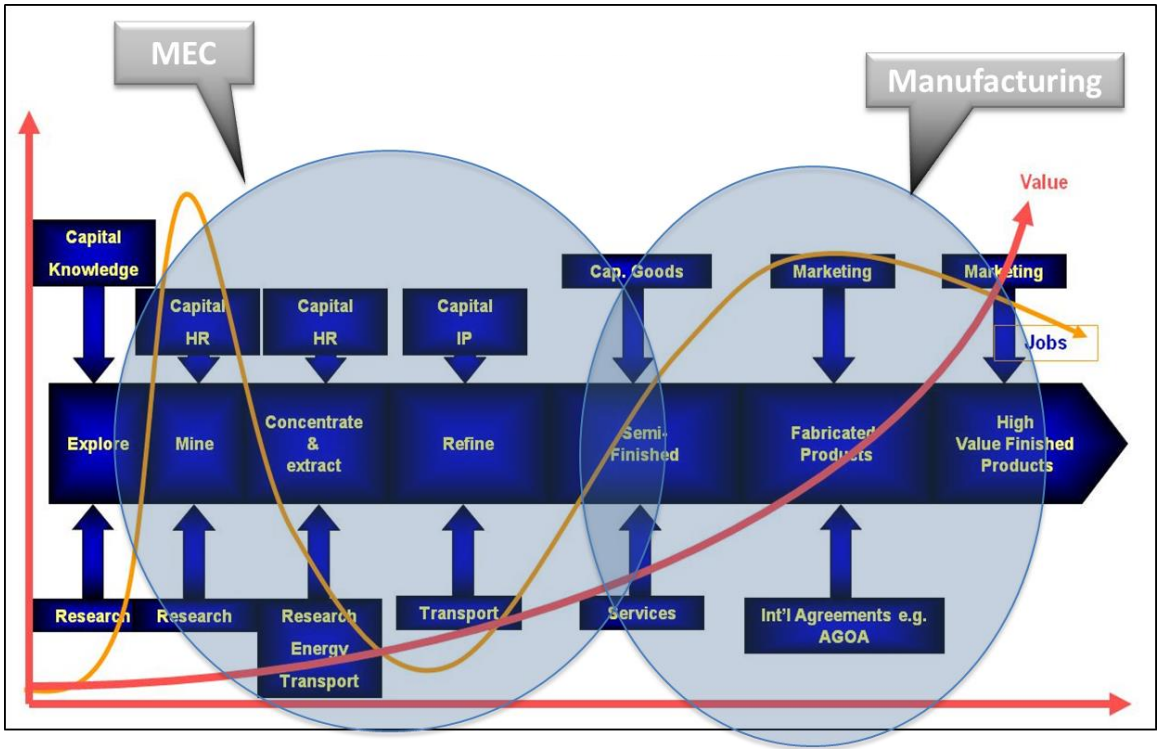


Figure 2-2: Relative position of companies in a mineral-energy complex to manufacturing companies along the mineral value chain (adapted from Mtegha, 2009).

In South Africa, forward linkages or mineral beneficiation within the mineral sector is carried out at different levels along the mineral value chain by a number of agents. To this effect, the government is pursuing mineral beneficiation under the South African Beneficiation Strategy where specific minerals are targeted (see Table 1-3). Mineral beneficiation depends on several things, chief among them are the importance of the mineral endowment in the global trade, the country's factors of production in particular human resource development (HRD), the level of research and development (R&D), and political will.

Mineral beneficiation has the potential to create nodes along the mineral value chain, and each node is capable of creating its own backward linkages engulfing a number of firms as its own captured suppliers. There could however be an overlap of suppliers across different nodes. Figure 2-3 shows a typical forward linkage effect for mineral resources with each node along the value chain having its own captured suppliers due to the backward linkage effect.

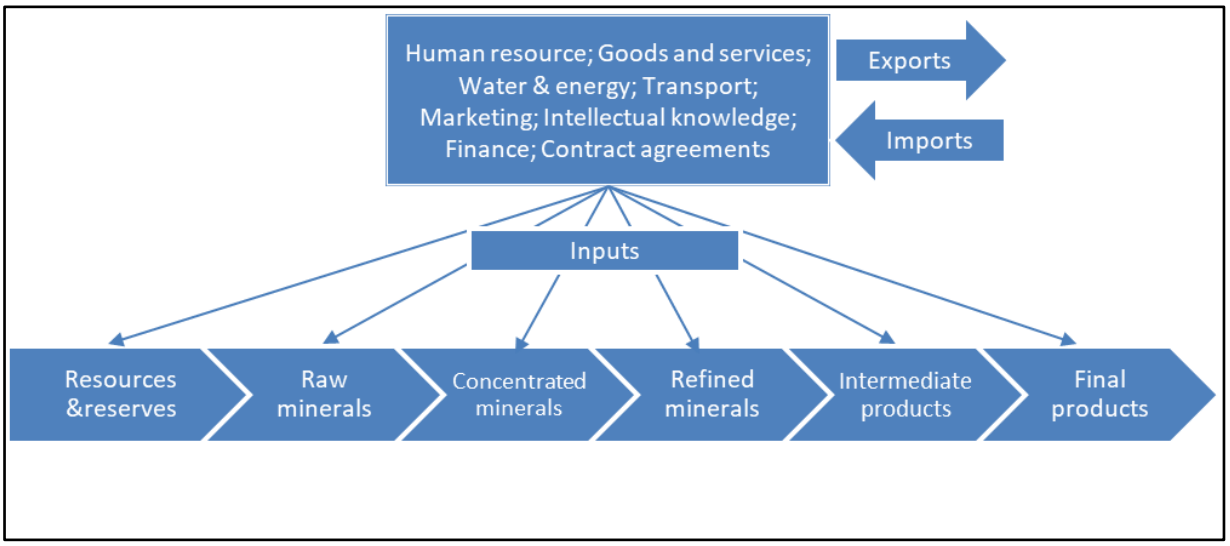


Figure 2-3: Inputs along beneficiation nodes in the mineral sector.

2.3.1.2. Backward linkages

Backward linkages, which are deemed far more critical in developing countries than the forward linkages by Hirschman[9], refer to the pulling effect of inputs required to produce products of economic value by base industries. The economic effectiveness of backward linkages stems from the inducement factor of the base industry of a large number of light engineering factories that are characterised by low capital intensity and relatively high labour absorption to supply inputs. In developed economies this phenomenon can occur at every subsequent node formed along the value chain.

As mentioned earlier, the mining industry in South Africa has managed to induce mining production supplier companies for both domestic and international markets within the backward linkage envelope. According to Walker and Jourdan (2003), South Africa has a competitive advantage in "shaft sinking and hoisting technology, cooling of deep mines, rock mechanics design, mining explosives, drilling equipment and abrasives, metallurgical processes and plants, and delivering intellectually based services to mines around the world".

The success of linkages, in particular backward linkages, depends on the success of business clusters, which basically "are geographic concentrations of firms, suppliers, support services, specialized infrastructure, producers of related products, and specialized institutions (e.g., training programs and business associations) that arise in particular fields in particular locations" (Porter, 2007; p. 1). The location of mining companies in the West Rand of the Gauteng Province in the 1900s and the Oliver

[9] Hirschman was a proponent of raw material exports during the early stages of economic development in a developing country. He argued that the focus should be on establishing domestic supply industries to supply the base industry with inputs and later when the economy is well established, then forward linkages can be undertaken.

Tambo International Airport in Ekurhuleni Metropolitan gave rise to manufacturing clusters in Ekurhuleni. Similarly, the location of headquarters of mining companies in Johannesburg gave rise to clustering of consulting firms in Johannesburg.

According to Porter (2007), clusters consist of large, medium, and small companies, and the preponderance of job creation in the past decades has been with small and medium companies. If the base industry is economically imperative to the extent that there is a political will to support venture clustering around it, over time it will result in side-stream linkages in addition to the already existing backward and forward linkages.

2.3.1.3. Side-stream linkages

Side-stream linkage effects occur within the backward linkage and arise when companies involved start supplying products and services not only to the base industry, but also to each other. The envelope in this case is characterised by knowledge, core-competency and expertise to satisfy the needs of a particular industry. The higher the importance and strength of the base industry, the bigger the envelope.

According to Lydall (2009) side-stream linkages within the backward linkage can manifest in the form of vertical, horizontal or technological linkages. This phenomenon is described by Lydall as a network of firms of different sizes (small, medium, and large), levels of technology (high and low technology) and focus areas (specialisation). Companies in the backward linkages are classified as tier 1 or tier 2 companies (see Figure 2-4).

Tier 1 companies almost exclusively supply the base industry with inputs, and they represent pure backward linkages. Tier 2 companies supply the base industry and/or

other suppliers with inputs. Those that exclusively supply other suppliers and not the base industry with inputs represent pure side-stream linkages. While the latter firms are not directly supplying the base industry with inputs, together with the backward linkage companies, they owe their existence and composition on the base industry.

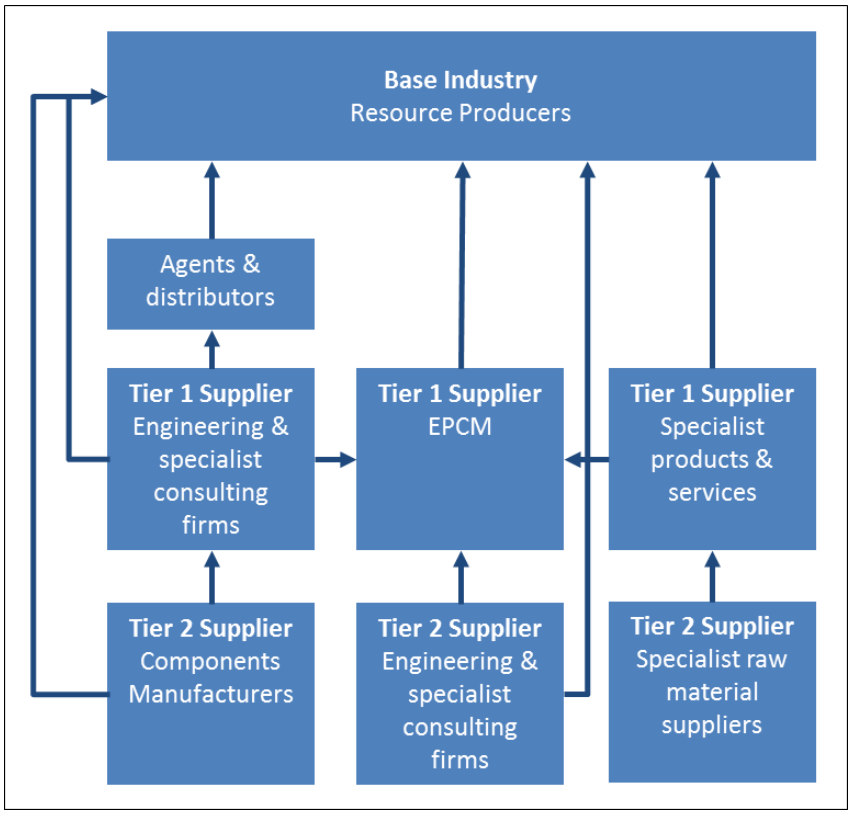


Figure 2-4: A model for the base industry supply chain as adapted from Lydall (2009).

2.3.2. Consumption linkages

The consumption and fiscal linkages, unlike the production linkages that are driven by movement of products and services between sectors (input-output driven), are income driven. Consumption linkages are defined as the “stimulus toward domestic production of consumer goods that will be undertaken as newly earned incomes are spent on such goods” (Hirschman, 1992, p. 64). This state arises when trenches of the initial

investment create the base industries that in turn result in primary income multipliers (see Table 1-4).

According to the theory, when the income level rises, purchase patterns change, and people can afford to buy imported goods. Over time, subject to the attractiveness of the home market, domestic firms will be established to manufacture goods and provide services that were initially imported. This can be done under import substitution or a competitive environment wherein the latter domestic firms can compete openly with their international counterparts. In the modern global trade regime, among others, it will require a high entrepreneurial factor to develop home-grown industries to produce goods and services for local and export markets.

It is important to note that while consumption linkage can be traced back to the base industry as its stimulus, it manifests away from the base industry in industries that are sometimes unrelated to the base industry (Hirschman, 1992). For example, mining can result in consumption of fashionable apparel, establishment of supermarket chains or increase in food production because of the expenditure of disposal income by households of employees in the mining industry on food, clothes and luxury items.

The downside of the consumption linkages is the obliteration of traditional artisanal forms of production (Hirschman, 1981) and the distortion of income distribution resulting in maladies such as inequality and poverty especially in rural areas. Furthermore they can be undermined by global trade liberalisation, resulting in a failure to establish domestic manufacturing and service provision capacity (Kaplinsky, 2011).

2.3.3. Fiscal linkages

Fiscal linkages arise when tax receipts of exports out of the enclaved productive activities or imports into the staple production are used by the state to invest in spatial linkage projects or to create new industries. It should be noted that consumption linkages are largely subjected to market forces, while fiscal linkages arise due to a deliberate move by the state to intervene in the markets. According to Hirschman (1981: p. 68) “fiscal linkages depend on the willingness of national governments to tax, or otherwise to claim participation in the incomes originating in mining and similar enclave-type enterprises”.

Hirschman called linkages associated with exports of enclaved productive activities, direct fiscal linkages and those linked with imports into the staple production, indirect fiscal linkages. Of the two types, the sources of direct fiscal linkages are easy to identify and isolate especially when enclaved enterprises are owned by foreigners as is the case with mining in many countries. Sources of indirect linkages are however not easily identifiable, because they are usually embedded in the production linkages owned or controlled by locals with political connections and power to influence policy. The best strategy in this case is to tax imports that are critical to the staple production, and over time institute policies that encourage importers to invest in domestic production. In this way, domestic production linkages will be encouraged.

The downside of fiscal linkages are misdirected investments, i.e. using tax income to invest in *white elephants*, support social programmes that do not enhance staple production, and encourage rent seeking behaviour of the state (Davis, 1998 and

Stevens, 2003). The misuse of fiscal linkage taxes throttles the effectiveness of spatial linkages to invigorate the domestic economy.

2.3.4. Spatial linkages

Spatial linkages are infrastructure that is built as a result of the exploitation of a resource in a country or a region (Jourdan et al., 2012; and Stiglitz et al., 2013). Such infrastructure was referred to by Hirschman (1958, p. 83) as Social Overhead Capital (SOC) which is defined as "basic services without which primary, secondary and tertiary productive activities cannot function". These include provision of public services such as law and order, health, education, water, power, communications, and transport. Hirschman (1958, p. 83) stated that the "investment in SOC is advocated not because of its direct effect on final output, but because it permits and in fact invites DPA[10] to come in". Notwithstanding the importance of other forms of SOC, power, communications, and transportation are crucial for the successful exploitation of resources and creation of base industries in endowed countries, while those such as law and order, education and health ensure that established linkages are sustainable.

The installation of SOC can be undertaken by the state, private companies involved in the exploitation of resources, or public private partnership (PPP); which is a partnership between the latter and the state. In the case of the state built SOC, the spatial linkages can precede or be the consequence of fiscal linkages. In the case of private initiative or even PPP, SOC will give rise to the social multiplier of the exploited resource as explained in Table 1-4.

[10] DPA stands for Directly Productive Activities.

With respect to private provision of infrastructure, while not disregarding social multipliers in Table 1-4, one way of creating spatial linkages is to develop or participate in spatial development initiatives (SDI) or corridor developments. The SDI concept originated in South Africa and its main objective is to enhance or entrench the benefits of resource linkages, especially mining resources. SDIs need anchor projects or sources and terminal ports or sinks to function (see Figure 2-5). They are best suited for mines producing bulk material where a link (e.g., rail, road or pipe) between the source and the sink can be procured under a concession agreement between the owners of the anchor project and the provincial or national government. The SDI concept dictates that revenue generated from the sale of products (e.g., metal ores) should be large enough to cover operational and maintenance costs of the link under concession.

The concession should be such that the concessionaire can sell additional capacity to other parties (nodes) at cost or subsidised rates to enable transportation of non-mining goods and other business opportunities along the corridor. This phenomenon is called densification of the link or trunk and it underpins economic growth. Typical examples of corridor development in the Southern Africa are the Maputo Development Corridor, a link between Mpumalanga coalfields in South Africa and the Port of Maputo in Mozambique, and the Zambezi Valley Development Corridor, a link between the coal fields of the Tete Province in Mozambique and the Port of Beira (Mtegha et al., 2012).

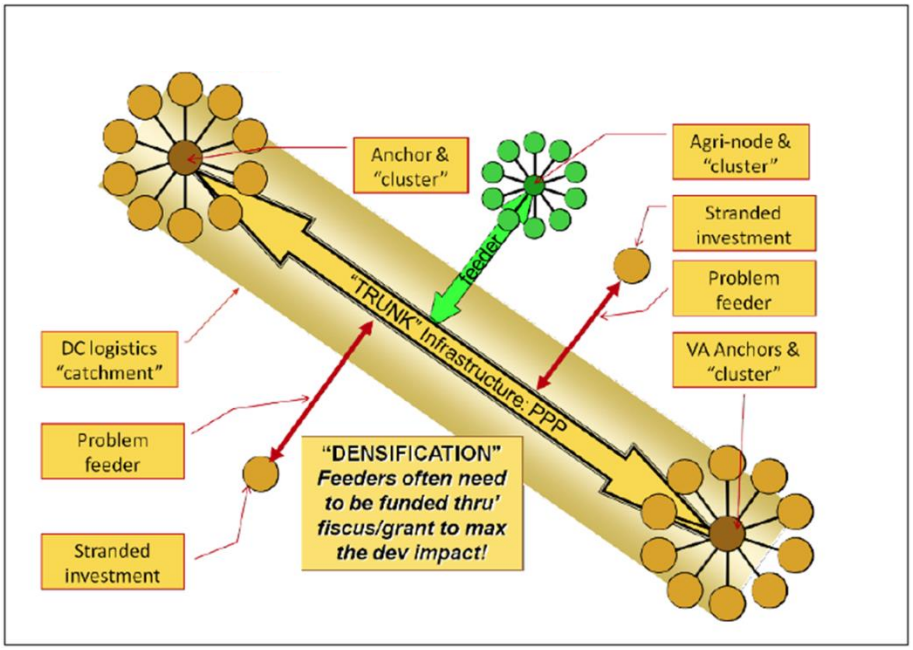


Figure 2-5: Idealised spatial distribution initiative configuration (Jourdan, 2011, in Mtegha et al., 2012).

2.3.5. Lateral migration linkages

Lateral migration refers to the adaption of technologies originally used in one industry to meet new demands in other industries as the consequence of the natural evolution of companies and economies (Walker and Jourdan, 2003; Lorentzen, 2006; Lorentzen, 2008; Lorentzen & Pogue, 2009; and Lydall, 2009). It can also be described as technological spill over effects into other industries. Lateral migration is underpinned by knowledge intensity, i.e. through the process of learning, assimilation and interaction between product/service providers on one hand and with the base industry on the other. The interaction between suppliers and clients can lead to the emergence of the knowledge-based activities over time. Some of these activities might not even be related to the base industry and in some cases, they may aggregate into a whole new industry. For example, the heavy machinery original equipment manufacturer (OEM) industry of the Scandinavian countries, which in itself own its existence to the

mining industry, has precipitated the ICT industry that enhances the performance and precision of mining machines.

Lateral migration has a broad spectrum of extensity that can be achieved through organic growth or acquisition. On the one end of the spectrum are backward linkage companies that through organic growth, constantly improve their position to a point where they eventually break out of their founding mould into other industries while remaining loyal to their initial focus point. Generally, these companies are specialists in niche markets and over time have undertaken minor technological modifications to their products in order to target other industries. For example, Bell Equipment initially developed tri-wheeler vehicles for harvesting sugarcane and later adapted these vehicles for the construction and timber logging industries[11]. Furthermore, Bell modified some of its product lines that were originally manufactured for the logging industry for application in the construction industry and later mining industry.

On the other end of the spectrum are backward linkage companies that through acquisition of other companies with technological competitive advantage, have managed to move from their original focus point to a destination that is completely foreign to their original founding mission. For example, Nokia Corporation started as a wood pulp mill and through series of acquisitions in its 150-year life span, transformed into a cable and rubber company (among others), then a cellular phone company and lately a mobile network provider[12].

[11] Source: Bell Africa, Detailed history at http://www.bellequipment.com/en/about-us/detailed-history

[12] Source: Nokia Corporation, Our story at http://company.nokia.com/en/about-us/our-company/our-story

2.4. Manifestation of backward linkages

Backward linkages are critical to the objectives (both primary and secondary) of this thesis. In the sections below in this chapter, four case studies are used to gain a deeper understanding of the manifestation of backward linkages. To this effect, Chile, Sweden, Australia, and Ghana were chosen largely because they have a long history of mining, are on different continents, and are considered as strong mining countries in their respective regions. In analysing mining backward linkages in these countries, this chapter looks at the general economic and political overview of each country, overview of mining and significant minerals mined, and the general manifestation of linkages.

While there may be other forms of linkages in these countries, the focus of this thesis is on backward linkages. The understanding of how backward linkages manifest in the four countries used as case studies, will aid in understanding the general political and economic environments that are crucial in bringing about meaningful backward mining linkages.

2.4.1. Chile

2.4.1.1. General overview

Chile is a long strip of land in South America (Latin America) with the Pacific Ocean on the west and the Andes Mountain range on the east. It is divided into 15 administrative regions as shown in Figure 2-6. Chile is a multiparty democratic country headed by a President.

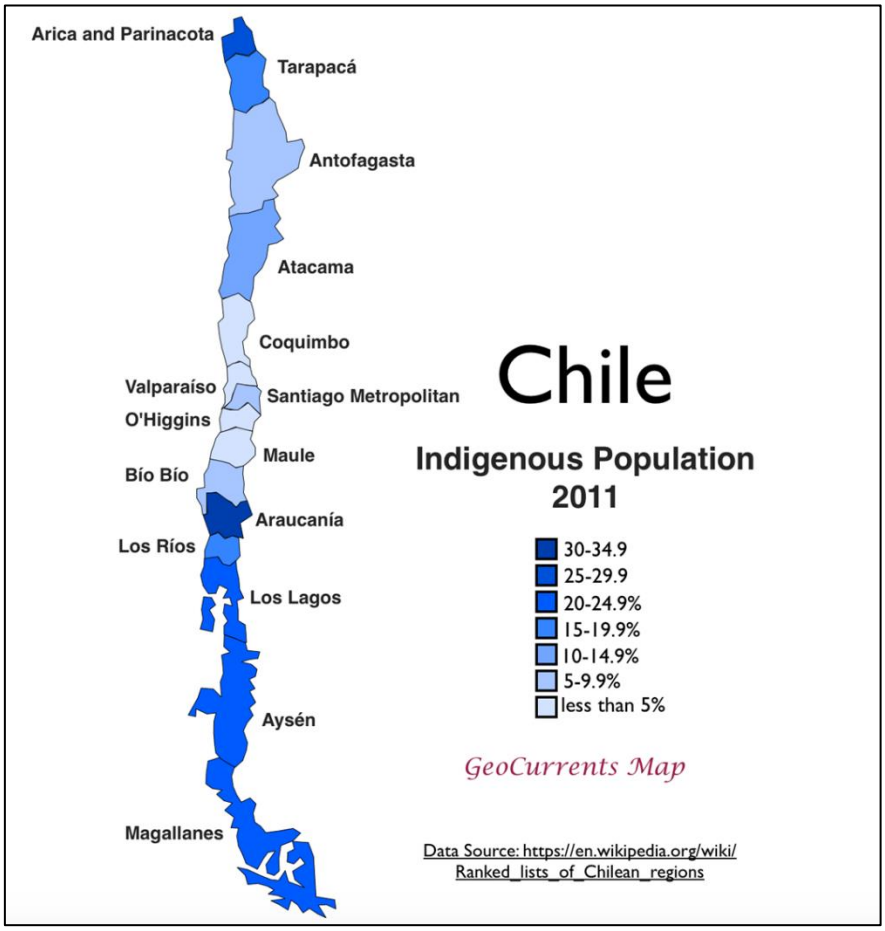


Figure 2-6: Map of Chile showing its 15 regions[13].

According to the World Bank (2018), Chile had an estimated population of 17.8 million people with GDP/Capita of US$14 907 (in 2010 constant prices) in 2015. Its population can be described as homogeneous, consisting approximately of 70% mixed race (mestizos), 20% Europeans, 5% Amerindians (International Council on Mining & Metals, 2007). It is a highly urbanised country, with about 85% of the population in the early 2000s already living in urban areas. The country's capital is Santiago, a home to approximately a third of the country's population.

[13] Source: http://www.geocurrents.info/cultural-geography/mapping-chiles-indigenous-population

The economy of Chile is highly skewed towards services. In 2003, the services sector contributed 54% to the GDP, the industrial sector's contribution was 27%, while mining's contribution was 8%, and that of the agricultural sector was 5%. On the export side, Chile is highly reliant on mining. In 2003, mining exports accounted for approximately 42% of the total exports (copper export accounted for 37% of the total exports), agricultural exports accounted for 37.1%, and manufactured products accounted for 15.6% (International Council on Mining & Metals, 2007).

In 2004, copper exports rose to 50% of the total exports. By 2010, the mining sector's contribution to the country's GDP was 15% and mining exports had reached 66% of the total exports, driven mainly by the buoyant price of copper (International Council on Mining & Metals, 2007, International Council on Mining & Metals, 2012, and Korinek, 2013). Countries whose mineral resource export is greater than 25% of the total exports account are described as mineral dependent (Hagland, 2011). Using this benchmark, Chile can be described as a mineral dependent country, particularly dependent on copper.

2.4.1.2. Mining in Chile

The modern history of mining in Chile stretches as far back as the 1850s when copper was mined in parts of the Atacama Desert in the Antofagasta Region (Region II). The Atacama Desert is a host to the world's largest deposits of copper, iodine, and lithium, and significant deposits of silver and molybdenum (Arias et al., 2014). In the 1860s, the discovery of sodium nitrate as an essential ingredient in the manufacturing of smokeless gunpowder replaced copper as the premier export commodity (Aroca, 2001). The discovery of sodium nitrate resulted in the mining boom and catapulted the

Antofagasta Region into the world's most important source of the mineral. Just before the commencement of World War I (WWI), Chile was exporting over 3 million tonnes of sodium nitrate. During and after WWI, Germany (one of the main importers of nitrates then) was cut off from the global trade of nitrates, resulting in the global collapse of the nitrate market, and consequently the emergence of synthetic substitutes. This led to the decline of the Chilean mining industry and the depression of the economy for more than a decade (International Council on Mining & Metals, 2007).

The current prominence of copper as the premier mining product in Chile started in 1928, driven mainly by mines in the Antofagasta Region (Aroca, 2001). Table 2-1 shows seven of the largest copper mines in the region and the year in which production started. Corporación del Cobre de Chile (Codelco), in Table 2-1, is a State owned mining company established in 1976 following the nationalisation of privately owned companies in 1971. It has some of the world's largest known copper resources in the world and operates copper mines such as El Teniente, Chuquicamata, Rodomiro Tomic, and El Abra (51% Freeport McMoran and 49% Codelco)[14].

Mining in the 18th and 19th centuries in the Latin Americas was an enclaved system that created an illusion of a positive contribution to the economies of countries in that region (Arias et al., 2014). This enclaved nature of mining later resulted in a friction between locals and foreign capital. In the 1960s, amid the growing uneasiness about the foreign ownership of mines in Chile and its enclaved nature, the government

[14] Source: www.codelco.com

passed a law that allowed 51% State ownership of copper mines in an effort to localise mines (International Council on Mining & Metals, 2007).

Table 2-1: Start of production of seven of the large copper mines in Antofagasta Region (International Council on Mining & Metals, 2007).

Mine	Owners	Start of Production
Chuquicamata	Codelco[15]	1910
Escondida	BHP Billiton, Rio Tinto, Japanese Escondida Consortium, International Finance Corporation	1991
Mantos Blancos	Anglo American	1954
Zaldivar	Placer Dome	1995
Michilla	Antofagasta Minerals	1994
El Abra	Freeport McMoran (51 %), Codelco (49 %)	1996
Lomas Bayas	Falconbridge	1998

In 1970, when Salvador Allende was the president of Chile, the State adopted pro-poor socialist policies that culminated in the nationalisation of industries (including mining) in 1971. Allende's socialist policies resulted in a bloated public sector, budget deficit, erosion of national reserves, and hyperinflation. He was deposed in a miltary coup in 1973 and was succeeded by pro-capital and military Commander-in-Chief, Augusto Pinochet. Under Pinochet, socialists and their supporters were repressed and the nationalisation policy was reversed. However, the nationalised copper assets were retained and housed under Coldelco. As a consequence, Codelco became one of the biggest copper mining company in the world.

[15] Corporación del Cobre de Chile or Codelco in short is a State owned mining company. Chuquicamata Mine was previously owned by USA based Anaconda Copper Mining Company. Source: https://www.lonelyplanet.com/chile/chuquicamata/background/history/a/nar/752766ad-a573-4516-9fc0-63b51ca4a0a0/1317460.

The Pinochet administration invited multinational companies to reinvest in the Chilean mining sector. In the late 1980s, a consortium consisting of BHP Billiton, Rio Tinto, Japanese Escondida Consortium, and International Finance Corporation was the first significant multinational company to return to Antofagasta under the new regime (International Council on Mining & Metals, 2007). Figure 2-7 shows the impact of foreign direct investment on copper production in Chile, particularly after 1990.

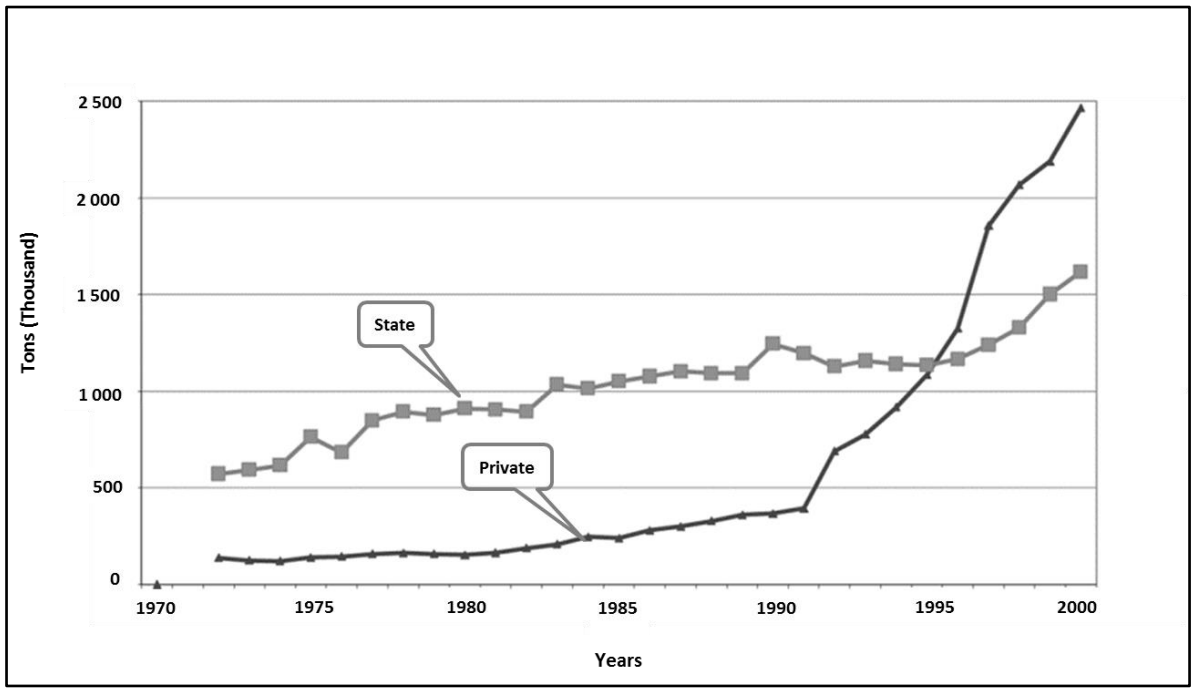


Figure 2-7: Comparison of copper production by Codelco and private companies in Chile from 1973 to 2000 (Aroca, 2001).

It is evident in Figure 2-7 that while Coldelco (State) is the biggest producer of copper in Chile, the combined output of the private sector (foreign direct investment or FDI in short) surpassed that of the State since the mid 1990s. While the Pinochet's administration was described as an authoritarian military regime, his leadership in re-opening up the country for foreign ownership of mines was successful in increasing the Chilean copper production.

2.4.1.3. Mining backward linkages in Chile

Most of mining in Chile, and for that matter copper mining, takes place in the Antofagasta Region. This region exported 96% of its mining production and accounted for approximately 50% of the Chilean mining output in 2010. This is considerable when taking into account that Chile was the largest producer of copper globally, producing 35% of the world copper production in 2010, with a 40% share of the global copper export in the same year. It is worth noting that the Antofagasta Region contributed 30% of the total Chilean exports in 2010 (Arias et al., 2014).

Between 1990 and 2003 the Antofagasta Region had managed to reduce the percentage of the local population living in poverty from 34% to 11%, the lowest in the country (International Council on Mining & Metals, 2007). This feat was attributed to the concentration of mining in the region and the resultant jobs created during the construction and operation of mines.

Aroca (2001) was of the view that during the development and production phases, mining in the Antofagasta Region created more mining jobs than there were local job seekers. To satisfy this demand, he estimated that 10% of the mining workforce was sourced from other regions. After calculating multipliers associated with mining consumption linkages in the Antofagasta Region using open and closed systems (Figure 2-8), Aroca (2001) concluded that commuting workers have a significant bearing on the local economy. In a situation where it was assumed that commuting mine workers working in the Antofagasta Region spent all their extra income in their home regions (open system), mining was significantly linked to business services, utilities and retail sectors in the Antofagasta Region. When it was assumed that they

spent their extra income in the Antofagasta Region (closed system), mining was significantly linked to seven sectors as shown in Figure 2-8.

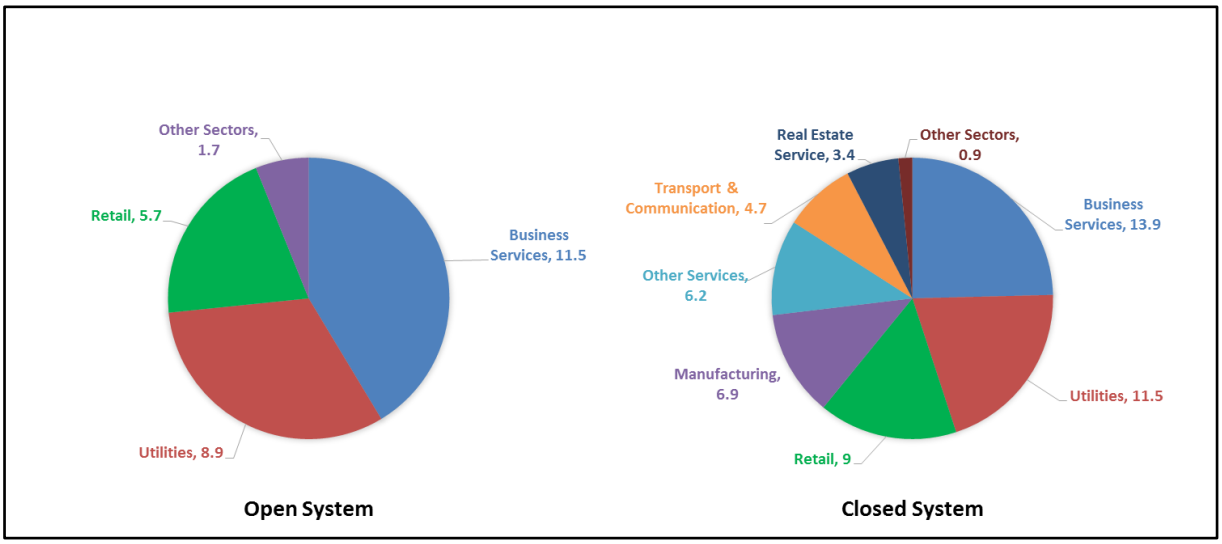


Figure 2-8: Comparison of open mining linkages under open and closed systems in the Antofagasta Region (Aroca, 2001).

Furthermore, Arias et al. (2014: p. 85) were of the opinion that there was “notably the delocalization of the backward linkages in the mining sector” in the Antofagasta Region. That is, mining in the Antofagasta Region also created employment multipliers associated with backward linkages in other regions. The job creation of mining in the backward linkage in Chile was supported by Atienza et al. (2018) when they pointed out that by 2013 there was a network of over 4 000 mining services companies. In 2015, mining services companies collectively employed 67.7% of people that work on the mines in Chile through outsourcing.

The work of Bas and Kunc (2009) in Arias et al. (2014: p. 85) showed that “89% of the main suppliers in the Chilean mining sector are located in Santiago (the capital of Chile), of which 65% do not have branches outside of *[sic]* the capital”. Atienza et al. (2018) also pointed out that 54.2% of mining services suppliers are in the Santiago

Metropolitan Region, 25.8% are in the Antofagasta Region and the balance is spread out among other regions.

This situation has resulted in segregation of the levels of work, where high-level workers such as managers and senior engineers are based in the Santiago Metropolitan Region where head offices of mining companies are, and lower level workers such as technologists, artisans, and operators work on sites located mostly outside Santiago Metropolitan Region.

Traditionally multinational mining companies in Chile outsourced non-core services such as transport, food and cleaning services to local enterprises, while core services were imported. According to Atienza et al. (2018), this can be attributed to Chile having a large number of mining services suppliers that are predominantly small to medium in size which are focused on generic supplies. The reliability of output and capacity of these suppliers were generally below the mines' expectations, hence there was a general preference of imports. Consequently, this limited home-grown solutions in mining.

Bas and Kunc (2009) in Arias et al. (2014) found that between 1976 and 2006, only 9% of companies in the mining cluster in Chile had registered patents with United States Patent and Trademark Office. Out of the said 9%, 99.74% were multinational companies and only 0.26% were local companies. However, Bravo-Ortega and Muñoz (2015) found that between 2000 and 2014 there were 2 069 patents registered by Chilean companies within the mineral sector. This is an indication of the growth of meaningful backward linkages in Chile after the introduction of developmental oriented policies and several development programs since 2000 as shown in Figure 2-9.

This was as the results of the combined efforts of State agencies such as National Economic Development Agency, National Commission for Scientific and Technological Research, Regional Development Agencies, and mining companies such as BHP Billiton and Codelco. The state agencies influenced and formulated relevant developmental policies (see Figure 2-9) and facilitated in their implementations to foster mining linkages clusters, particularly among small and medium size local companies. Mining Companies developed and participated in the capacity building programmes such as the World Class Mining Suppliers Program (Bravo-Ortega and Muñoz, 2015 and 2021).

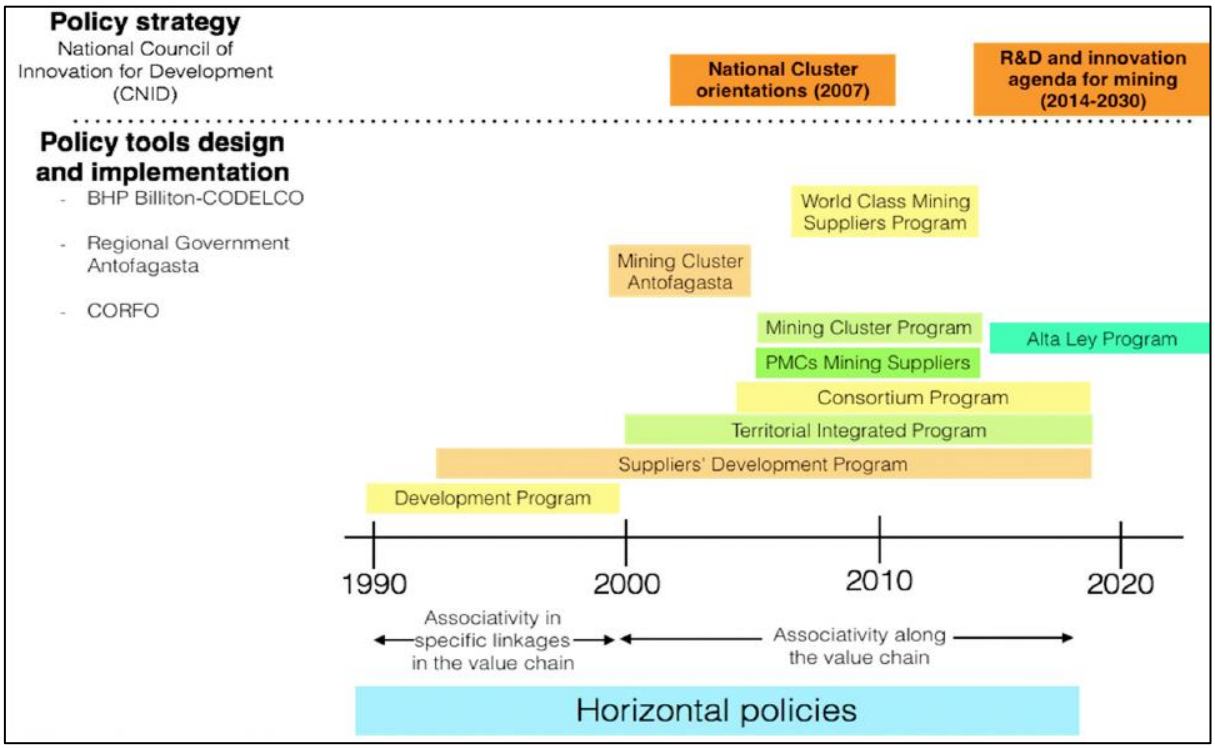


Figure 2-9: Chilean policies and mining inputs supplier development programme that are attributed with growth of supplier companies in Chile between 1990 and 2020 (Bravo-Ortega, and Muñoz, 2021).

2.4.2. Sweden

2.4.2.1. General overview

Sweden is one of the Nordic countries in northern Europe and it can be described as a postindustrial country. In 2015, it had a population of 9.9 million people with 7.5% unemployment rate and had a GDP per capita of US$55 395 in 2010 constant prices (Statistics Sweden, 2016 and The World Bank, 2018).

The economy is strong and well managed with a budget deficit of approximately 2% and a national debt of 40% of the GDP in 2014, although in terms of economic size is dwarfed by the likes of the USA, Germany, France, and Japan among others within the Organization for Economic Co-operation and Development (OECD) as shown in Figure 2-10. The country's assets position by far exceeded its liabilities in 2016 (BBC News, 2016). Sutherland (2015) described Sweden as politically and economically stable with a healthy banking system and low inflation (-0.05% in 2015).

Sweden has a mixed economy system, a combination of command and market economy systems. The model of the economy in Sweden is informally called the Swedish Model, which at its core is public private partnership and fair labour practices. The Swedish model is also characterised by centrally negotiated wages, high personal income tax, and highly subsidised social security and welfare. These social benefits have contributed to high living standards and long life expectancy, which are thought to be among the best in the world (BBC News, 2016).

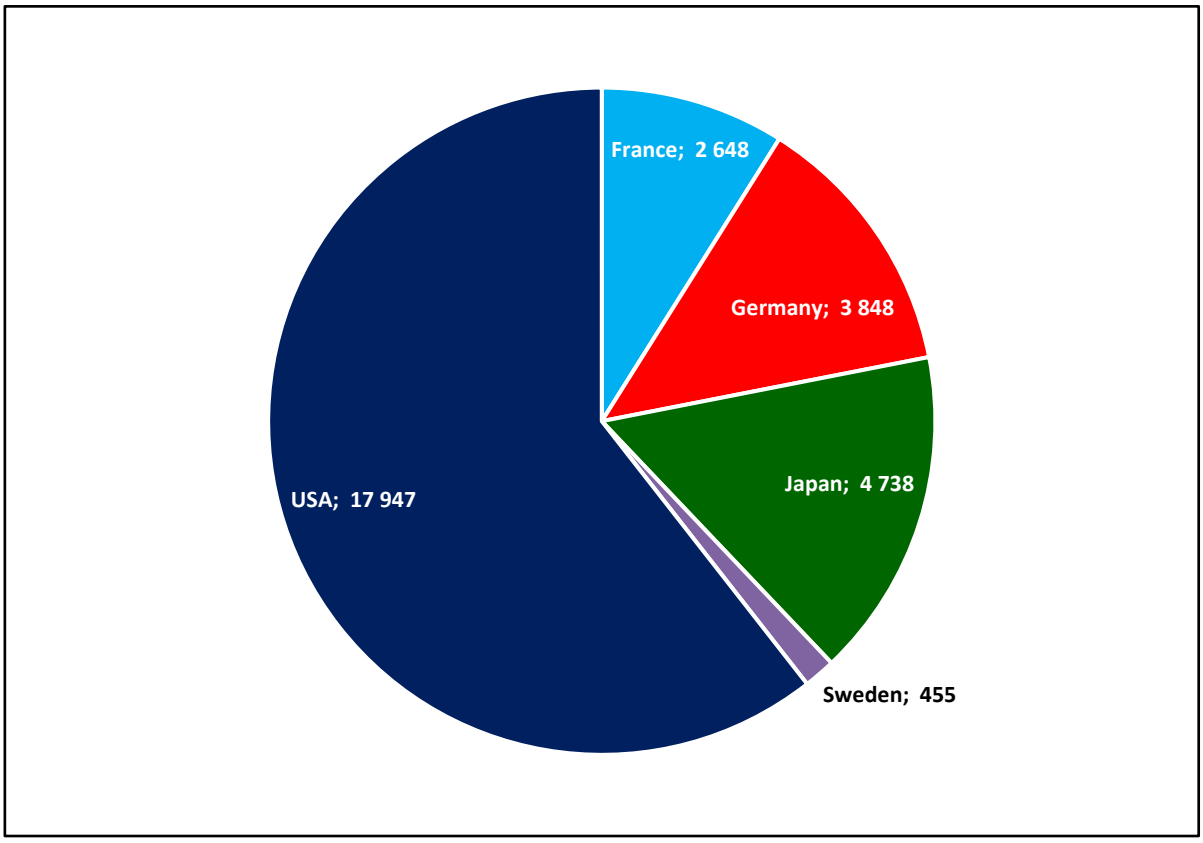


Figure 2-10: The 2015 GDP of selected OECD countries in million US$[16].

The Swedish economy is export oriented and it can be observed in Figure 2-11 that machinery and vehicles were the predominately exported goods at 16% of the total export account each in 2013, followed by pharmaceutical products at 13%, wood products and electronics at 11% each, and minerals at 10% (Sutherland, 2015). When the financial sector was excluded in 2014, manufacturing (engineering) and wholesale and retail trade sectors stood out as key sectors in the Swedish economy as shown in Figure 2-12.

[16] Source: Aggregate National Accounts, SNA 2008 (or SNA 1993): Gross domestic product (https://data.oecd.org/gdp/gross-domestic-product-gdp.)

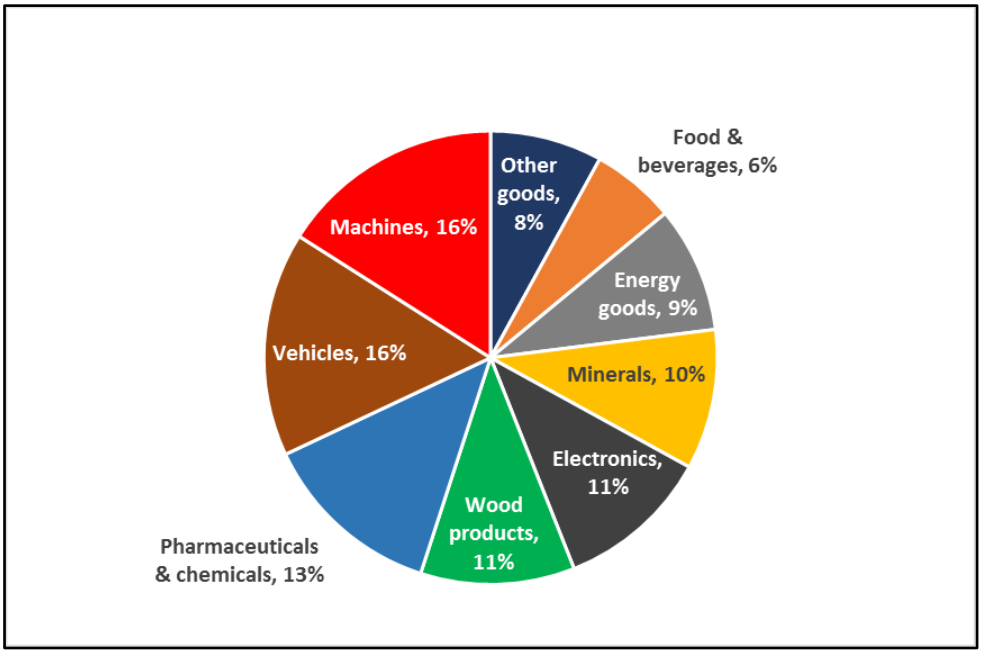


Figure 2-11: Percentage distribution of Swedish goods exports in 2013 (Sutherland, 2015).

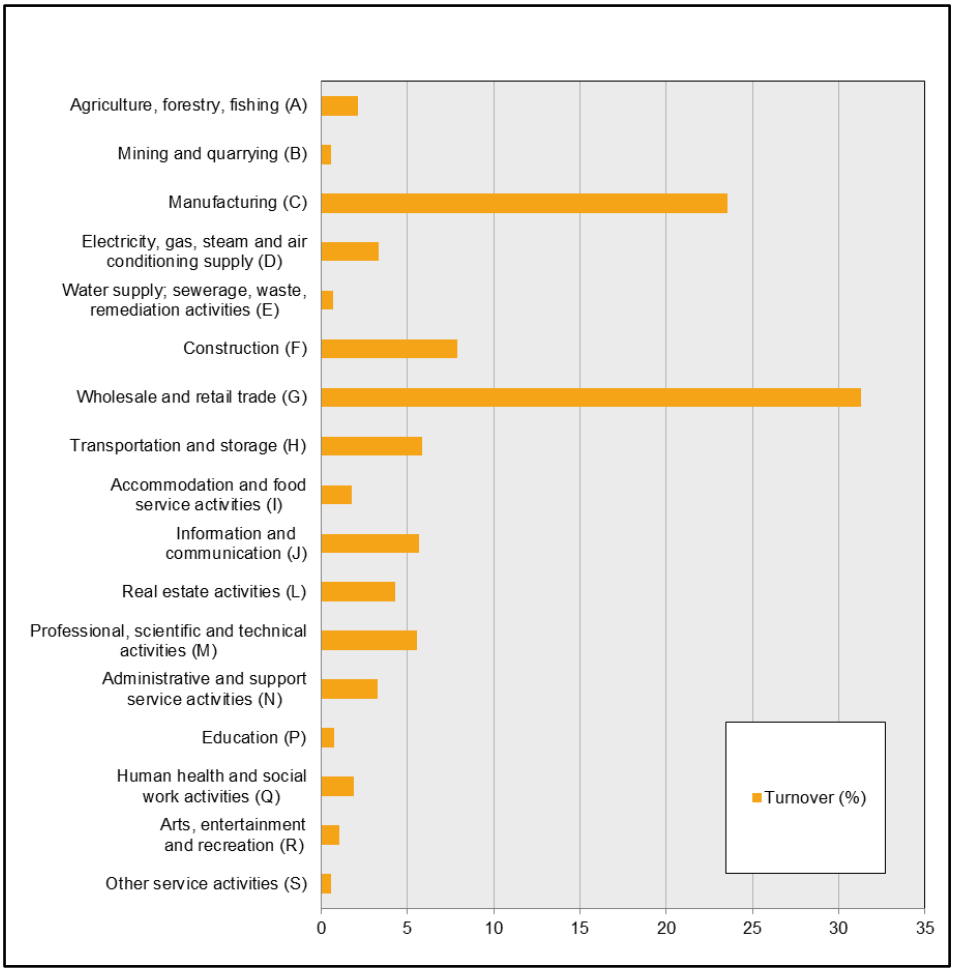


Figure 2-12: Percentage share of turnover by industry in 2014 in Sweden when the financial sector was excluded (Statistics Sweden, 2016).

2.4.2.2. Mining in Sweden

Sweden is a leading metal mining country in Europe. In 2010 mining contributed 0.87% to the country's GDP (Swedish Ministry of Enterprise, Energy and Communications, 2013). Mining in Sweden is part of a mining cluster that consists of mining, equipment and technology and services companies. The collaboration within the mining cluster is over 100 years old and in 2013 its contribution to the GDP was estimated at 1.3% (Tillväxtanalys, 2016).

There is considerable mining activity in the Nordic countries, with Sweden being one of the leading mining countries in the European Union (EU). Within the EU, Sweden alone accounted for approximately 90% of iron ore production, 32% of lead production, and 23.5% of zinc production in 2015. Sweden and Finland together accounted for 70% of gold and 21% of silver production of the total EU output in 2015. There are a number of operational mines in Sweden including State owned Luossavaara-Kiirunavaara Aktiebolag's Kiruna mine, the biggest underground iron ore mine in the world. Most of the mines in Sweden are in the northern part of the country (Vihersaari, 2015 and SevMin, 2012).

Mining in the northern part of Sweden, a region rich with minerals, dates as far back as the 17th century. The mining of phosphorus-rich iron ore in the Northern Norrland (see Figure 2-13) took off around 1890 largely due to developments in the processing technology and improvement in the railway transportation. In the late 1900s intense global competition and rationalisation within the Swedish mineral sector resulted in the depression of mining activity for a period close to 30 years. However, the renewed global mineral demand in the early 2000s resulted in the resurgence of mineral

exploration and even the reopening of dormant mines or upscaling of capacity in some of operational mines in the Northern Norrland (Tano et al., 2016). By 2015, there were 25 active junior international mining companies in Sweden (Vihersaari, 2015).

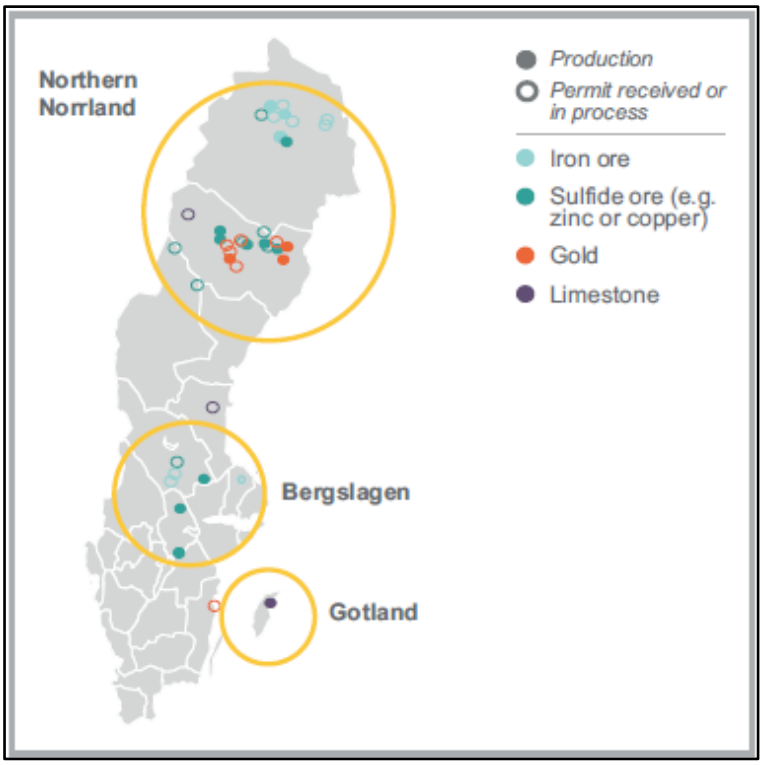


Figure 2-13: A map showing locations of operational mines and mining permits in Sweden (SevMin, 2012).

Two of the major mining companies in Sweden are Luossavaara-Kiirunavaara Aktiebolag (LKAB) which is a 100% state owned company, and Boliden Group, (Vihersaari, 2015). LKAB is a diversified company that includes mining, mineral processing, logistics, drill rigs and mineral products manufacturing, research and development, and property management (which includes building and construction). The company describes itself as “a high-tech international minerals group, world

leading producer of processed iron ore products for steelmaking, and a growing supplier of mineral products for other industrial sectors"[17]

The Boliden Group is a vertically integrated company encompassing mineral value chain interests that include mineral exploration, mining, mineral processing, and minerals marketing. The company has six mining areas in Europe, three being in Sweden. It also has five smelters and one refinery across Europe, with only one smelter in Sweden[18].

2.4.2.3. Mining backward linkages in Sweden

The backward and forward linkages in Sweden are extensive, manifesting in a strong relationship between mining companies, equipment manufacturers, and mineral services companies as shown in Figure 2-14 (SevMin, 2012). San Cristobal and Biezma (2006, p. 3), stated that in Sweden "manufacture of machinery and equipment; land transport and transport via pipelines; sale, maintenance and repair of motor vehicles and construction are the main sectors whose products are used as inputs" into mining.

In the work done by San Cristobal and Biezma (2006), it was found that metal mines in Sweden have strong backward and forward linkages. Other sectors of mining like coal and lignite mining, non-metal mines and quarrying did not exhibit comparatively strong relationships with other sectors in around 2015. Nonetheless, the mining sector in Sweden can be described as a network of relationships between mines and suppliers with a tendency to outsource maintenance services to local OEMs, a feat that

[17] Source: http://www.lkab.com/en/About-us/Overview/; downloaded on 7/19/2016
[18] Source: http://www.boliden.com/About/; downloaded on 7/19/2016

strengthens backward linkages. Historically, LKAB played a crucial role in strengthening backward linkages by extending its outsourced services to several OMEs in Sweden. Only as late as in the second decade of the 21st century that it has started considering other international companies (Maley, 2014).

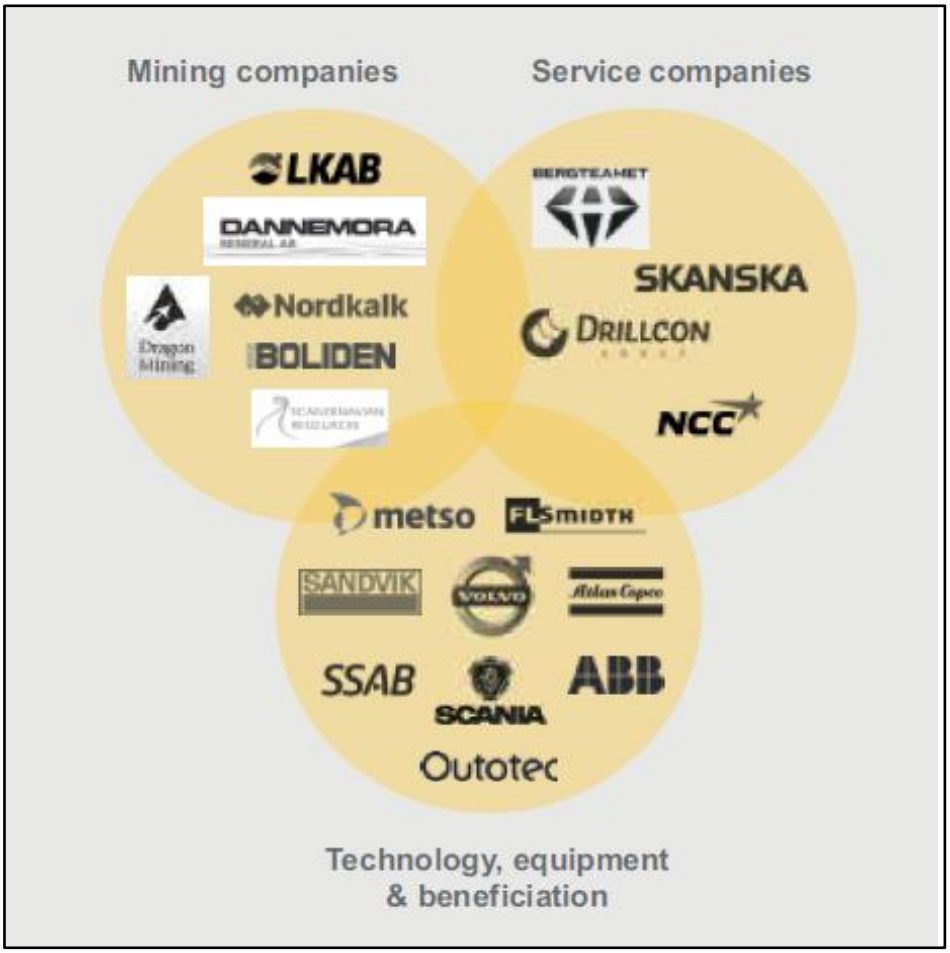


Figure 2-14: Relationship between mining companies, equipment manufacturers, and mineral services companies in Sweden (SevMin, 2012).

Swedish brands shown in Figure 2-14 are well-known in mining internationally. These are export-oriented brands that continue to be supported locally. The local support and export orientation of the Swedish OEMs has been forged over many years. Sandvik and Epiroc (formerly Atlas Copco) are good examples of mining OEMs in this regard.

These two prominent companies had significant market share in Sweden in 2011 as shown in Figure 2-15, and yet were strong competitive brands internationally.

The participation of Sandvik as a supplier to the mining industry can be traced as far back as 1907 when the company started producing hollow drill steels as one of the rock tool products (Sandvik Mining and Construction, n.d.). Similarly the participation of Epiroc as a supplier to the mining industry can be traced as far back as 1898 when it produced the first compressed air powered drill (Atlas Copco, n.d.).

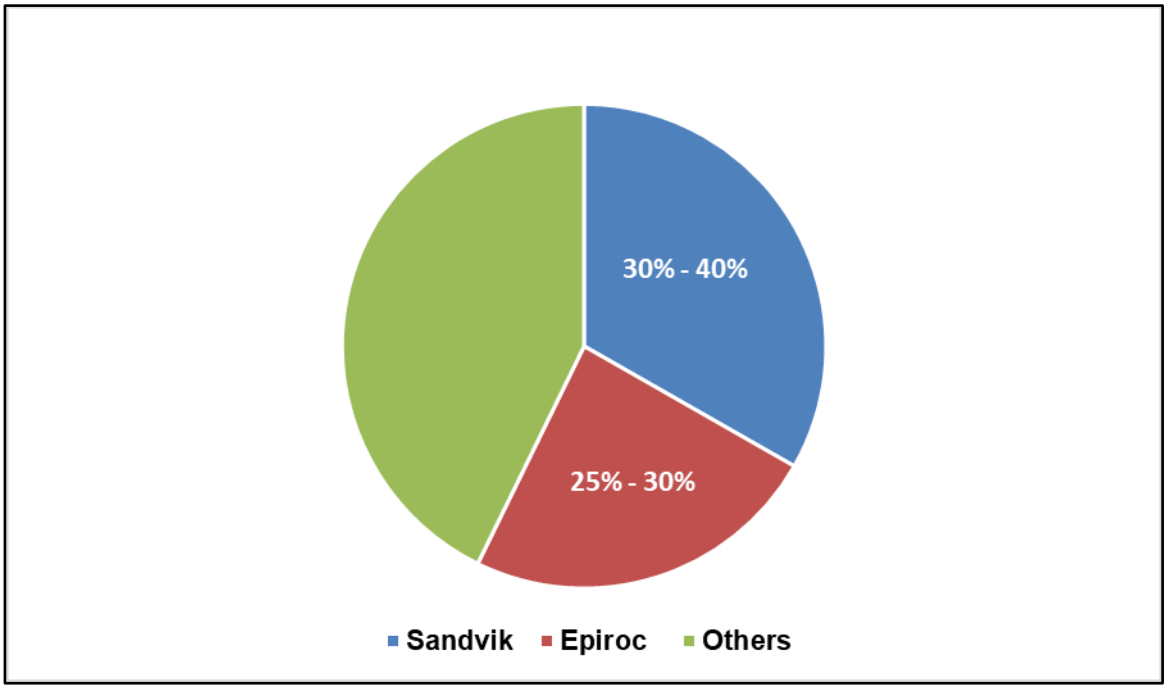


Figure 2-15: Market share of mining equipment suppliers in Sweden (SevMin, 2012).

2.4.3. Australia

2.4.3.1. General overview

The continent of Australia was inhabited by Aboriginal people about 40,000 years ago. European explorers came across the continent in the 17th century. It became a British colony in 1829 and gained independence in 1901 to form a federal parliamentary democracy government. Upon independence, the country was named the Commonwealth of Australia or Australia in short. By 2015 Australia was a prominent and developed country with memberships of a number of international organisations that included the Commonwealth Nations, G-20, Paris Club, OECD, and United Nation Security Council (temporary member) (IndexMundi, 2015).

The country is divided into seven territories with Canberra in the New South Wales territory as its capital city (see Figure 2-16). Mining activities are significant throughout the country, particularly in the Western Australia, Queensland, and New South Wales territories.

Australia has an open market economy with few restrictions on imports, a stable financial system that went through the 2008 financial crisis virtually unscathed, and low unemployment rate and public debt. In the past 20 years to 2012, the economy grew continuously at an average rate of 3.5% per year. The growth can largely be attributed to the growth in resource demand, particularly from China.

The strong performance of the resource sector at the back of high volumes of minerals such as iron ore, copper, and coking coal, contributed to the strengthening of the currency. Unfortunately, the strengthening of the currency unintentionally led to the

weakening of the manufacturing output and non-mining exports. Notwithstanding the preceding view, mineral resources constitute a significant portion of exports and consequently favourable terms of trade.

Figure 2-16: Map of Australia[19]

[19] Source: http://1.bp.blogspot.com/-6wv3-_jwUm8/T32nseJgUkI/AAAAAAAAAyg/2-EY4bdGiiA/s1600/Australia-politic-map.jpg

The estimated population of Australia in 2015 was 23.8 million (49% males and 51% females) compared to 21.5 million in the 2011 census. In the same census, it was determined that there were 17.36 million people who were 15 years old and above, 44% of whom had no qualifications, 45% had vocational training or post matric qualifications, and 11% had not stated their qualifications (see Figure 2-17).

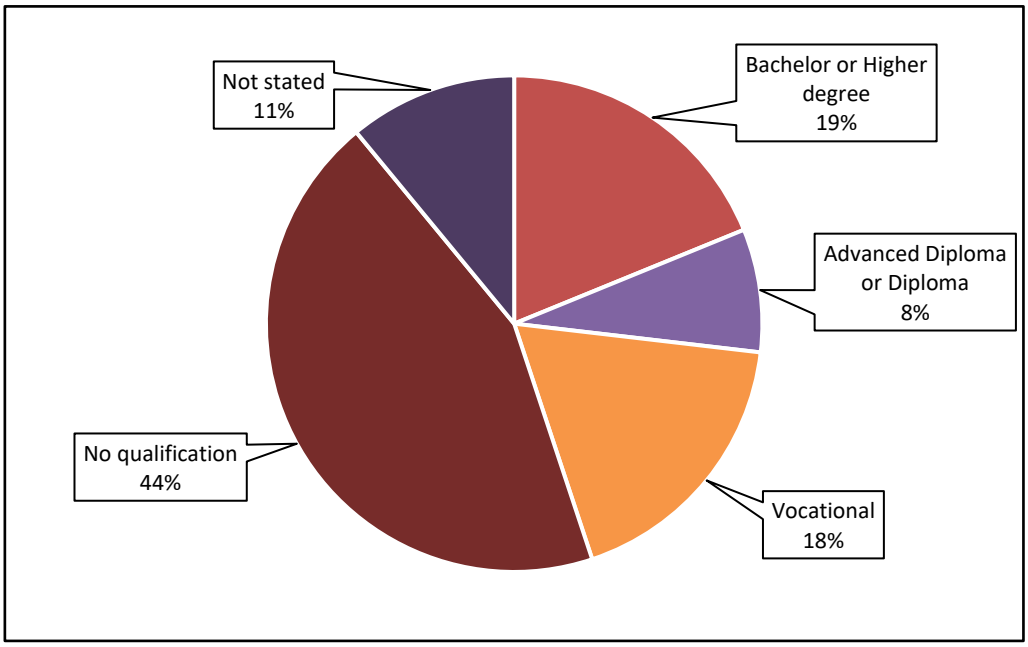


Figure 2-17: Qualifications of population 15 years and older in Australia (profile.id, 2015).

People in employment in 2011 were 10 million and Figure 2-18 shows employment by occupation based on the 2011 census. It will be noticed that many of those in employment are professionals (21%) and those with low skills (classified as labourers) constitute only 9% of employed people 15 years old and above in Australia (profile.id, 2015).

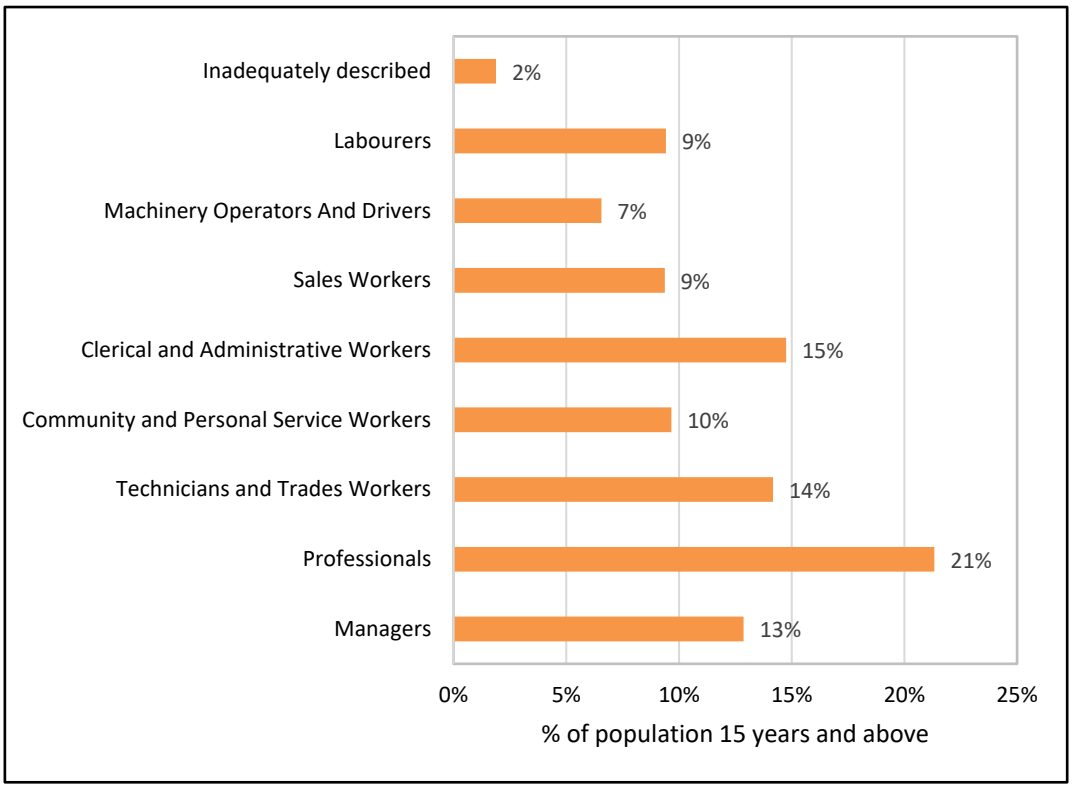


Figure 2-18: Occupation of population 15 years and older in Australia (profile.id, 2015).

Looking at Figure 2-17 and Figure 2-18, it can be deduced that the rate of employment is high among the educated people with formal training. It is therefore not a surprise that the GDP per capita of Australia was US$55 942 (in 2010 constant prices) in 2015 (The World Bank, 2018).

2.4.3.2. Mining in Australia

Australia is endowed with different minerals that include gold, iron ore, coal, copper, bauxite, diamonds, and uranium, but by far the biggest Australian mineral resource is iron ore although this was not always the case. The first mineral to be mined at significant economic scale was copper in 1842. However, the first mineral that brought Australia to the attention of the global mining community is gold, particularly after the 1851 gold rush (Mudd, 2007).

In the late 1930s there was a growing concern that the iron ore endowment of Australia was limited and would not last a generation. To this effect, numerous projects were initiated to establish the full extent of the endowment. Earlier reports indicated that iron ore resources of Australia were significantly limited and consequently there was an embargo on iron ore exports. Further exploration throughout the 1950s changed this view and resulted in a partial lifting of the embargo with restrictions such as 50% export of the resource provided the exported quantity was less than 1 Mtpa (ibid).

The rate of exploration for the iron ore deposits in the early 1960s increased due to the partial lifting of the export embargo and this resulted in an increase in the endowment from hundreds of million tonnes to billions of tonnes. By 1964 the embargo was completely lifted and by 2006 Australia was accounting for approximately 40% of the global iron ore export market. Mudd (2007: p. 41) stated that “throughout the 1960’s the known economic iron ore resources of Australia grew almost exponentially with iron ore production between 1960 to 1970 surging from 4.45 Mtpa to 51.22 Mtpa. The construction and development of these large-scale projects often tested the very limits of the technical and financial resources of the companies involved, which mostly rose successfully to the challenge. The various projects included new towns to service the mines, large railway infrastructure as well as new port shipping facilities”.

Australia has experienced a boom in mining investment from 2000 to 2013. According to Minerals Council of Australia (2017), the size of the mining industry in Australia in 2016 was three times bigger than in 2000. The contribution of the mining industry to the GDP of Australia has grown at an average growth rate of 6.5% from 2005 and by 2016 its contribution was approximately 9%. The mining industry accounted for 64%

of merchandise trade and 50% of total exports in 2016 (Minerals Council of Australia, 2017).

Downs et al. (2014, p. 1) estimated that the mining investment boom from 2000 to 2013 “raised real per capita household disposable income by 13 per cent, raised real wages by 6 per cent and lowered the unemployment rate by about 1¼ percentage points”. According to the Minerals Council of Australia (2017), the average salaries in the mining industry was 77% higher than the average salaries in other industries.

While the mining boom had largely benefited the Australian economy, it had negative effects in other sectors such as agriculture and manufacturing as shown in Figure 2-19 (Downs et al., 2014). These two sectors in particular are generally adversely affected by the appreciation of the currency. As the currency appreciates, so are input costs into these two industries to a point where imports become competitive and viable alternatives locally.

In a model developed by Downs et al. (2014) in Figure 2-19, it was forecasted that if the mining boom continued beyond 2013, mining output would have reached as high as 45% above its 2000 base in 2019 before trending downwards. According to the model, the prolonged mining boom would have adversely affected construction, property and business services, and distributional services sectors beyond 2013 in addition to consumer services, manufacturing and agricultural sectors that were already under severe pressure from the appreciation of the currency.

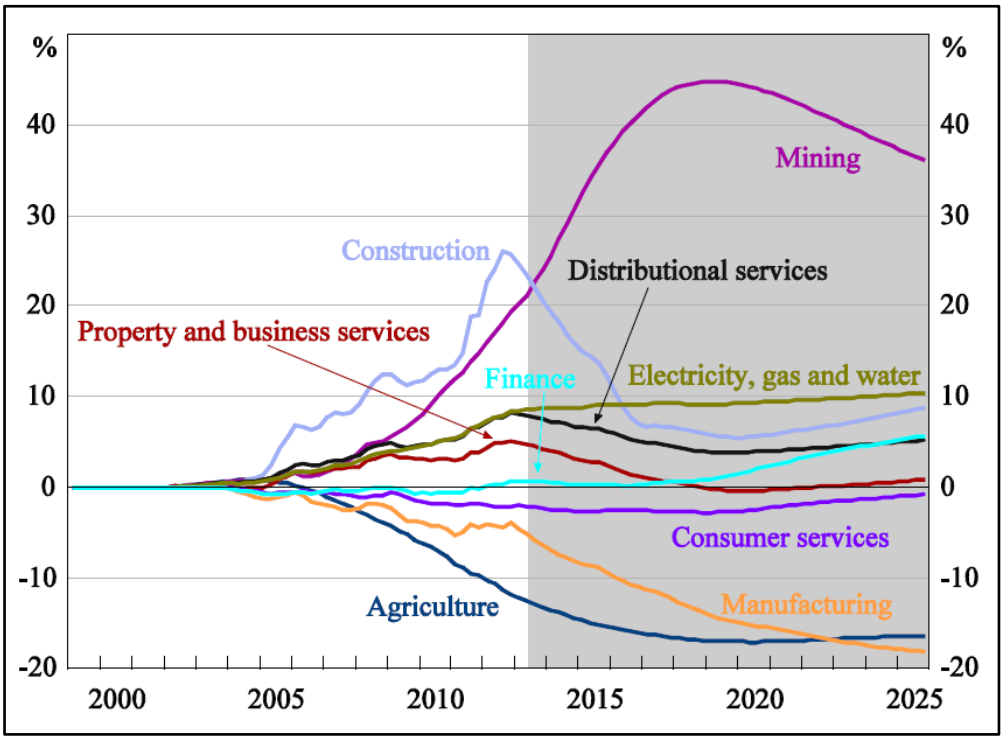


Figure 2-19: The model of the effects of mining boom on sectorial output in Australia (Downs et al., 2014).

2.4.3.3. Mining backward linkages in Australia

According to Scott-Kemmis (2013), since 2000 there was a 15 fold growth in the size of the sector comprising mining equipment, technology and services (METS) companies in Australia. By 2012 there were over 270 active METS that collectively contributed approximately 6.5% to the GDP, earned over Aus$71 billion, and their exported goods and services and offshore sales amounted to a value exceeding Aus$12 billion with an employment complement of approximately 265 000 people.

However, the Department of Industry, Innovation and Science (2019), indicated that in 2017/2018 there were 90 000 METS companies with approximately 6 700 of them generating annual revenue of Aus$2 million or greater and being responsible for 70% of the revenue of the METS sector. Furthermore 13% of METS companies employed

85% of employees in the METS sector while the remaining 87% only employed 5 employees each. Deloitte Access Economics (2017) estimated that METS companies in 2015/2016 generated Aus$133.2 billion in gross value added and supported 484 114 full-time equivalent (FTE) jobs. In addition, Deloitte Access Economics (2017; p. 11) pointed out the “defining the Australian METS sector is a more complex task, as there is no widely agreed or accepted definition of what activities are included in “METS”, and the breadth of industries that supply specialised inputs to the mining sector is wide”. This could be the indication of the complex linkages of the METS companies in Australia with the rest of the economy.

In the 2009 survey of the Australian METS companies by Tedesco and Haseltine (2010), it was shown that approximately 49% of employees had tertiary qualifications (7% of whom had doctorate qualifications), while a further 34% had trade or equivalent qualifications as indicated in Figure 2-20. Only 17% of employees did not have formal qualifications. This type of labour composition is indicative of the level of work (goods and services) provided by the Australian METS, hence the high level of innovation manifesting in a complex relationship between METS, mining companies, research institutions and universities as shown in Figure 2-21.

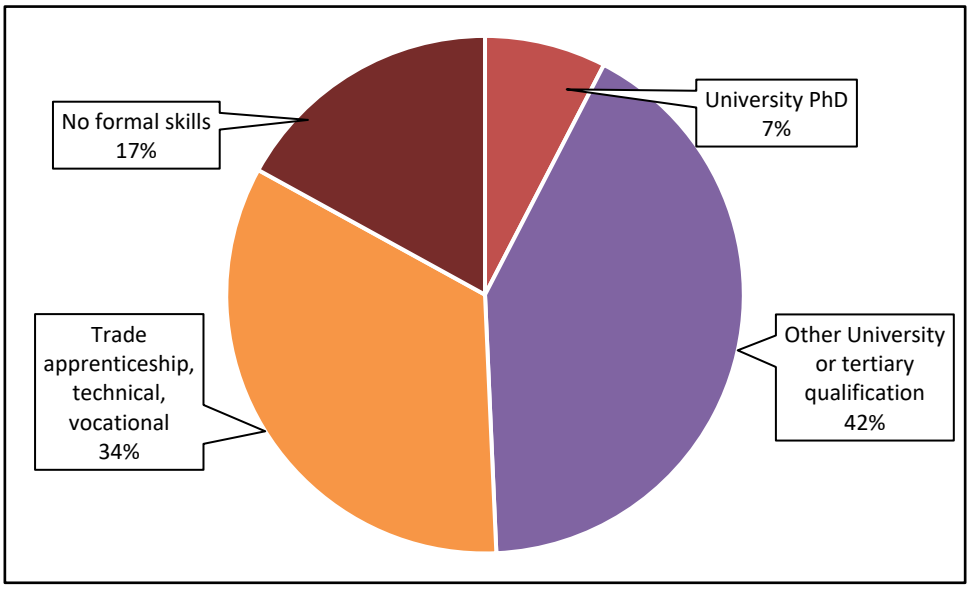


Figure 2-20: The distribution of employment by qualification within the Australian METS (Tedesco and Haseltine, 2010).

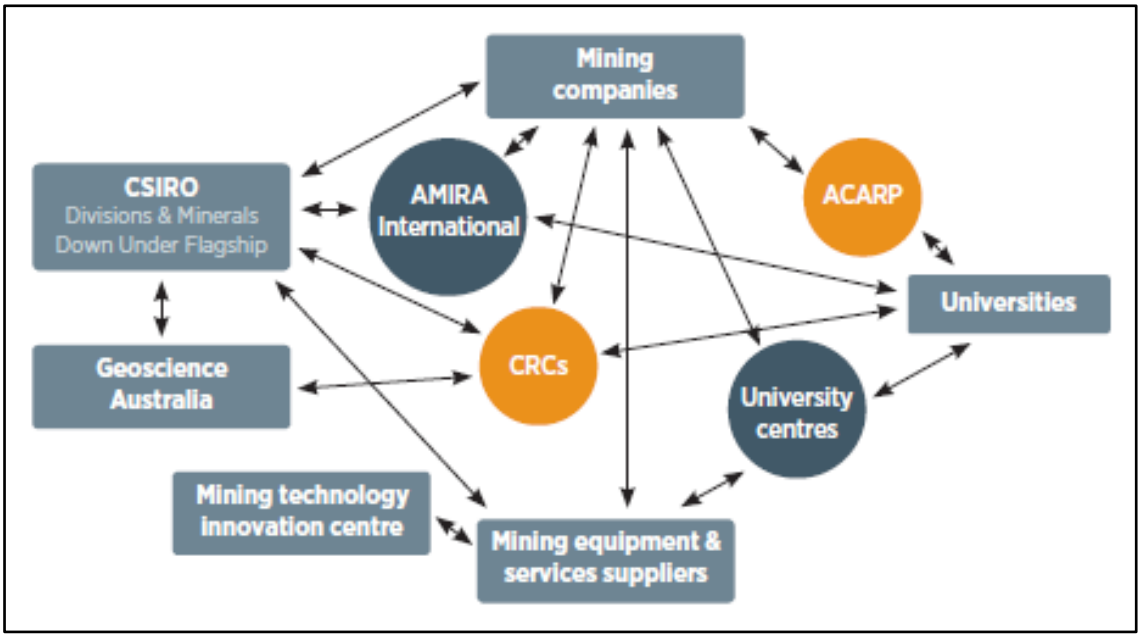


Figure 2-21: The innovation relationship complex within the Australian mineral sector (Kemmis, 2013).

Further analysis of the METS sector by Kemmis (2013, p. 24), revealed that "the largest segment includes those firms providing services – ranging from exploration to contract mining. The second largest group includes firms providing equipment for mine

development, mining and processing. The third, and fastest growing, segment includes those firms providing highly specialised technology – equipment, software and related services" (see Figure 2-22). Based on this analysis, it can be concluded that the Australian METS sector's strength lies in the provision of services and less on the manufacturing of goods. This is advantageous to Australia as Downs et al. (2014) in Figure 2-19 has demonstrated that services are less adversely affected by the recent mining boom compared to the manufacturing sector.

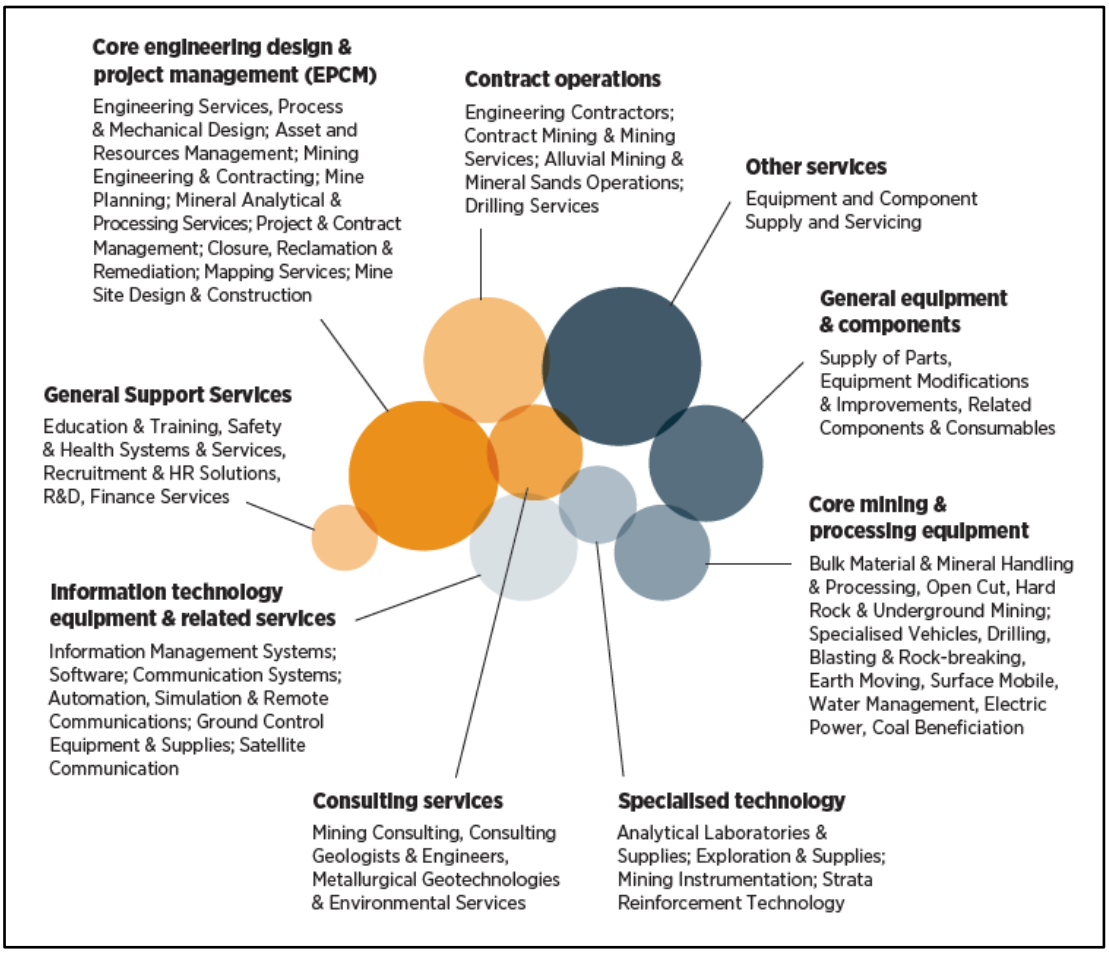


Figure 2-22: Broad spectrum of activities within the Australian METS (Kemmis, 2013).

2.4.4. Ghana

2.4.4.1. General overview

Ghana is one of the Anglophone countries in the western part of Africa with a population estimated at 28.3 million people in 2015 with GDP per capita of US$1 686 in 2010 constant prices (Ghana Statistical Service, 2016a and The World Bank, 2018). It is the first sub-Saharan African country to gain independence from British rule in 1957. The country is a multiparty democratic state headed by a president as both the head of state and government. The country is divided into 10 administrative regions, with Accra being the capital city (see Figure 2-23).

Figure 2-23: Administrative map of Ghana[20].

[20] Source: http://www.mapsopensource.com/images/ghana-regions-map.gif (accessed on 27/10/2016)

Kwame Nkrumah became the first elected president of Ghana in 1957. He advocated government policies based on Import-Substitution Industrialisation against the advice of agriculture focused economic policies by Arthur Lewis. He was removed from power in a 1966 military coup conducted under the leadership of Lieutenant General Akwasi Amankwaa Afrifa, among others, largely because of his autocratic leadership style and his failed economic policies which were exacerbated by the drought that affected cocoa yield. Cocoa was the main export commodity of Ghana which Nkrumah used to support domestic industrialisation. The new National Liberation Council regime that deposed Nkrumah consisted of military and police officers (Miller et al., 2009 and Jedwab and Osei, 2012).

Between 1966 and 1981 Ghana had seven heads of state, both civilian and military. In 1981, the Armed Forces Revolutionary Council selected Flight Lieutenant Jerry Rawlings to be the head of State in 1981 and in 1983 instituted structural reforms under the guidance of the World Bank and the International Monetary Fund. Between 1987 and 1989, he privatised stated owned enterprises which were nationalised in the early 1970s. He was democratically elected as the president of Ghana in 1992 and 1996 (Miller et al., 2009 and Jedwab and Osei, 2012).

The Ghananian economy can be divided into three main private sectors, namely agriculture, industry and services. Historically, agriculture was the main sector in the economy of Ghana, driven mainly by livestock, while cocoa was the main export product. Over time the services sector grew in size with the resultant labour migration from agriculture to the services sector, giving rise to the Lewisian economic development (Jedwab and Osei, 2012).

The manufacturing sector was historically the least contributor to the GDP among the three main private sectors. The output of the sector significantly dropped in the 1970s after the nationalisation of foreign companies and recovered slightly after the 1983 reforms of Rawlings. Since then its contribution to GDP has steadly appreciated and surpassed the agrarian sector for the first time in 2011 as shown in Figure 2-24 (Jedwab and Osei, 2012, and Ghana Statistical Service, 2016b).

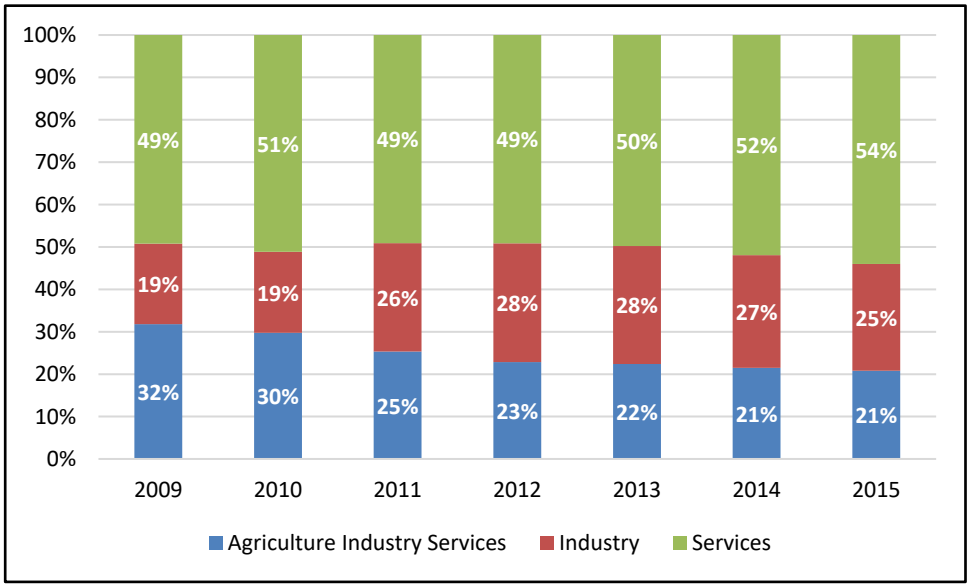


Figure 2-24: Percentage contribution of agriculture, industry, and services from 2009 to 2015 to the GDP of Ghana. (Ghana Statistical Service, 2016b).

In 2010, over 50% of people between the ages of 15 and 64 years in Ghana were employed in the agrarian sector (see Figure 2-25), a majority of whom were in the northern regions. The southern regions were significantly service orientated, with a majority being in the retail sector (Jedwab and Osei, 2012 and Alagidede et al., 2013).

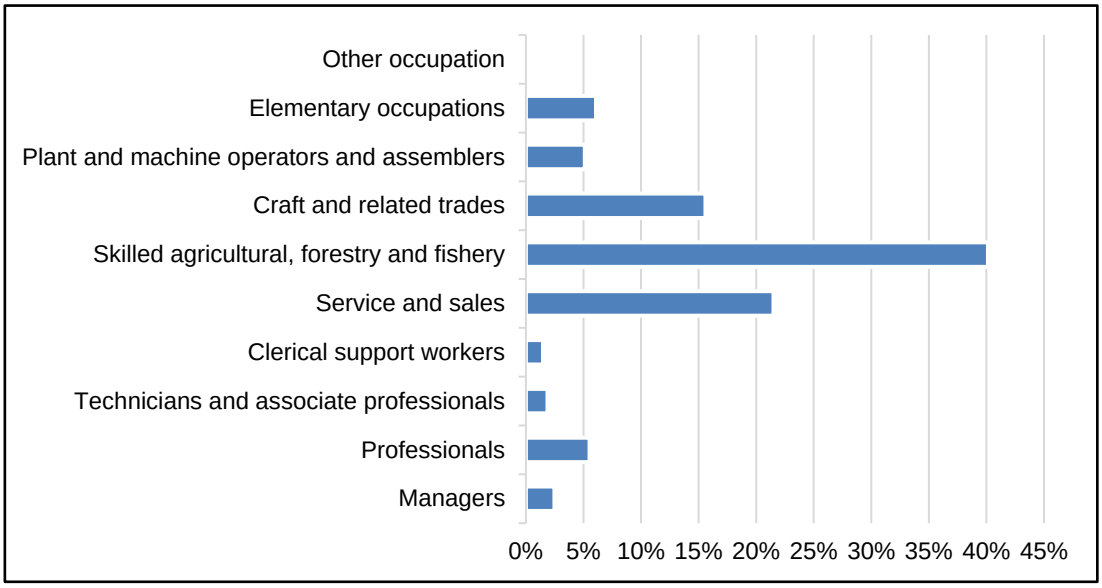


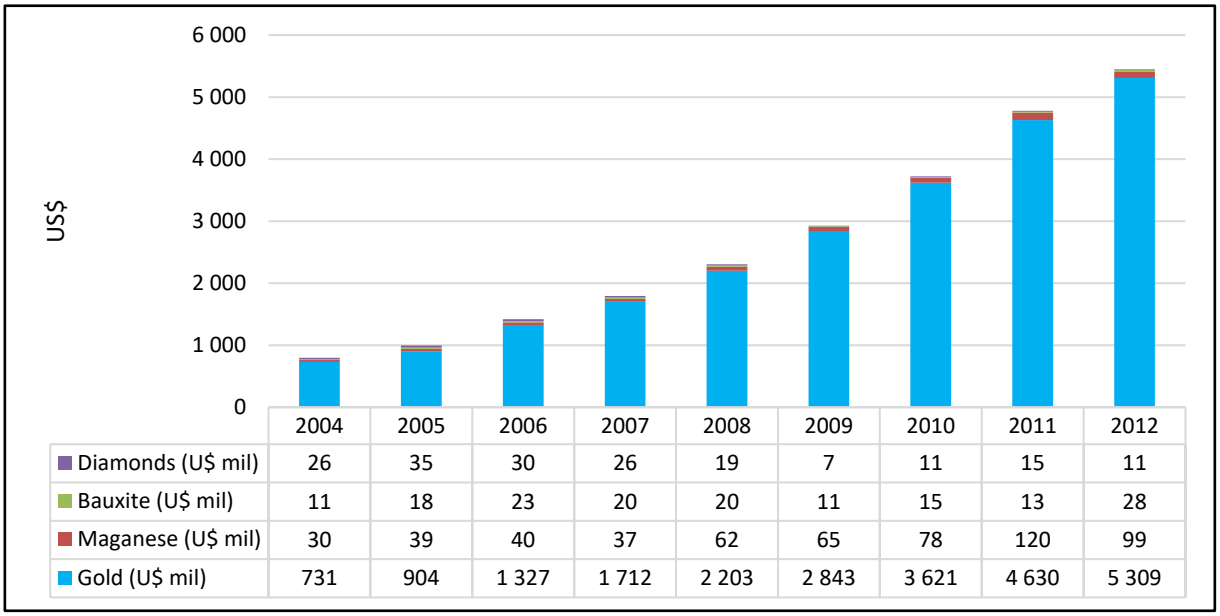
Figure 2-25: Employment per occupation in Ghana in 2010. (Statistical Service, 2016a).

Ghana has recovered from a devastating recession in the early 1980s and 1970s due to government instability and failed economic policies. The average annual economic growth rate between 1984 and 2010 was 5.2%. After the rebasing of the national accounts from 1993 to 2006, the average annual economic growth rate between 2007 and 2012 was 8.3%. Ghana recorded 15% real growth in GDP in 2011 due to the commencement of oil production (Alagidede et al., 2013).

In 2012, the Ghanaian unemployment rate was 3%, however this low rate of unemployment was partially attributed to discouraged job seekers. What is concerning about the employment in Ghana is the low rate of gainful employment. For example in 2010, only 23.5% of employed Ghanaians were in gainful employment, while the rest were in vulnerable employment (informal sector) with suppressed wages and likely not to have adequate social security (Alagidede et al., 2013).

2.4.4.2. Mining in Ghana

Mining in Ghana started long before the arrival of the Venetian explorer, Cada Mosto, in West Africa in 1455. The principal historical mineral mined in Ghana is gold. The country is endowed with several minerals, but the four main minerals mined on a large industrial scale as shown in Figure 2-26 are gold, manganese, bauxite, and diamonds.



	2004	2005	2006	2007	2008	2009	2010	2011	2012
Diamonds (U$ mil)	26	35	30	26	19	7	11	15	11
Bauxite (U$ mil)	11	18	23	20	20	11	15	13	28
Maganese (U$ mil)	30	39	40	37	62	65	78	120	99
Gold (U$ mil)	731	904	1 327	1 712	2 203	2 843	3 621	4 630	5 309

Figure 2-26: Revenue contribution of gold, manganese, bauxite, and diamonds in Ghana from 2004 to 2012 (Ghana Chamber of Mines, 2016).

Most of the large scale mines are found in the southern part of the country, namely Western, Central and Eastern regions (see Figure 2-23) and by far gold is the most important mineral, amassing over 95% of the mineral revenue from 2004 to 2012 (Ghana Chamber of Mines, 2015, and Ghana Chamber of Mines, 2016). However, the country has other minerals that are exploited on a low scale such as brown clays, silica sand and kaolin and others that are under exploited such as iron ore, limestone and columbite-tantalite (International Council on Mining & Metals, 2015).

Historically, mining has attracted a significant portion of FDI into Ghana and contributed significantly to the export account and fiscal revenue. For example, mining attracted over 50% of FDI into Ghana and accounted for 37% of the export revenue in 2013. The average export revenue contribution of mining between 2005 and 2013 was 41%. In 2013, mining contributed 19% to the tax revenue of the state. The contribution of mining to the country's GDP was 7.6% in 2015 (Economic Commission for Africa, 2018).

After the independence of Ghana from Britain, the state became a majority shareholder in non-Ghanaian mining interests. This was reversed in 1983 under Rawlings' presidency. The large scale mining is now largely foreign owned (76% participation in 2013 versus 24% local participation), with the state enjoying a 10% free carry stake in a majority of operations (International Council on Mining & Metals, 2015). Table 2-2 shows some of the major companies that were in operation in 2015 and the government's stake in them.

Table 2-2: Major mining companies in Ghana (International Council on Mining & Metals, 2015).

Company	Government Share	Main Mineral	Location in Ghana	Country of Origin
Adamus Resources	10%	Gold	Teleku-Bokazo and Nkroful (Western Region)	Australia
AngloGold Ashanti	1.7%	Gold	Obuasi (Ashanti Region) and Iduapriem (Western Region)	South Africa
Chirano Gold Mines	10%	Gold	Chirano (Western Region)	Canada
Ghana Bauxite Company	20%	Bauxite	Awaso (Western Region)	China
Ghana Manganese Company	10%	Manganese	Nsuta (Western Region)	Australia
Gold Fields Ghana	10%	Gold	Tarkwa and Damang (Western Region)	South Africa
Golden Star Resources	10%	Gold	Prestea and Wassa (Western Region)	Canada
Newmont Ghana	0%	Gold	Kenyasi (Brong Ahafo) and New Abirem (Eastern Region)	USA
Perseus Mining (Ghana)	10%	Gold	Ayanfuri (Central Region)	Australia
Prestea Sankofa Gold	10%	Gold	Prestea (Western Region)	Ghana

Alongside large-scale mining, there is a strong community of small-scale operations. Small scale mining is reserved for Ghanaians, but because of lack of capacity to regulate the sector, it was infiltrated by illegal miners. In 2014, the government deported about 5 000 foreign illegal small scale miners (International Council on Mining & Metals, 2015).

It is worth mentioning that Ghana has since 2011 started producing oil. In 2011, oil production contributed 5.4 percentage points to the country's 15% GDP growth (Alagidede et al., 2013). In 2016, the oil industry was the third biggest exporter after mining and cocoa, contributing 12.5% to the total exports. Mining and oil sectors accounted for 37.5% of all industrial activities in 2017, but accounted for only 0.8% of the total employment in 2015 (Economic Commission for Africa, 2018).

2.4.4.3. Mining backward linkages in Ghana

According to Bloch and Owusu (2012), mining supplier companies in Ghana are divided into four tiers. The first tier are companies that directly supply mining companies with goods and engineering services. The second tier are suppliers to the first-tier companies and the third tier comprise of indirect mining services suppliers. Lastly, the fourth tier consists of companies involved in indirect producer services to mining as shown in Table 2-3.

Table 2-3: Categorisation of gold mining suppliers in Ghana (Bloch and Owusu, 2012).

Tier level	Description	Products and services
First	Direct Suppliers	• Engineering and service providers (e.g., EPCM) • Original equipment manufacturers (OEMs) • Consumables input suppliers (explosives, chemicals) • Agents and distributors (pumps, bearings, vehicle parts)
Second	Indirect Suppliers	• Specialised engineering and services (electrical engineering, ventilation) • Component manufacturers • Manufacturers of standard components (cabling, electrical motor parts) • Manufacturers of specialised niche components (hoisting hooks, pinch valves) • Foundries and machine shops • Input providers (chemicals, steel products)
Third	Indirect Mining Services	• Geological, survey, land use planning • Laboratory services • Drilling services
Fourth	Indirect Producer Services	• Finance, insurance, real estate, & legal services • Transportation & logistics • Civil engineering, construction, environmental services, & landscaping • Catering, cleaning, & security

The government of Ghana introduced the Minerals and Mining (General) Regulations L.I. 2173 (L.I. 2173) in 2012. The L.I. 2173 was introduced mainly to increase local content in the procurement value of local mines. The intentions of L.I. 2173 rest on three pillars, namely increase in goods and services purchased locally; increase in participation of local businesses in local mines' procurement value chain; and increase in employment of local labour at various professional levels in the mineral sector (Economic Commission for Africa, 2018).

The Minerals Commission in Ghana moved to use procurement value of local mines in 2014 to quantify compliance to the intentions of L.I. 2173. To this effect, procurement value was divided into three parts, namely total procurement, total local procurement and true local procurement values (Economic Commission for Africa, 2018). Generally, procurement value points to the strength of backward linkages, particularly with first tier companies.

While total procurement value is the total cost of inputs into mines in Ghana, the local procurement value in this case entails “purchases by mining companies from firms based in Ghana irrespective of whether those firms were engaged in manufacturing activities locally, or whether they were local importers and agents representing foreign firms” (Economic Commission for Africa, 2018; p. 100). On the other hand, the true local procurement value entails “purchases of products manufactured in Ghana or sourced from Ghanaian service providers, who perform production-related operations within the country. This metric singles out those product categories where value is added in Ghana, although L.I. 2173 does not specify a threshold regarding value addition for the product to be categorized as “true local”” (Economic Commission for Africa, 2018; p. 100).

In 2014 and 2016 the Minerals Commission published a list of eight and nineteen items respectively (excluding water, diesel and electricity) that mines in Ghana must procure locally under the L.I. 2173. In Table 2-4, it can be noticed that the total procurement value of items listed by the Minerals Commission increased by 114.8% between 2014 and 2016; the local procurement value increased by 147.3% over the same period; and true local procurement increased by 44.1% over the same period (Economic Commission for Africa, 2018). The huge difference (103.2 percentage points) between the growth rates of local and true local procurement values suggests that despite the introduction of L.I. 2173, local suppliers still import inputs into local mines at a higher rate than local inputs.

Table 2-4: Procurement value of items listed by the Minerals Commission of Ghana under the Minerals and Mining (General) Regulations L.I. 2173 (Economic Commission for Africa, 2018).

Procurement Value	2014 (US$ million)	2016 (US$ million)	Growth rate
Total	183.8	394.8	114.8%
Local	148.2	366.5	147.3%
True Local	143.3	206.5	44.1%

The Economic Commission for Africa (2018) estimated that by 2016, mines in Ghana were still importing approximately 80% of their inputs (this is inclusive of items listed by the Minerals Commission). According to Bloch and Owusu (2012), Ghana in 2011 did not have a strong industrial sector that could supply complex technical products and services required by large mining companies. Most of the first-tier companies were agents of international companies, majority of which (about 80%) were located in Accra, with a few in Takoradi and Kumasi. The numbers in Table 2-4 suggest that lack of appropriate manufacturing capacity in Ghana was still a cause for concern even in 2016.

2.4.5. Discussion

The four countries discussed above, Chile, Sweden, Australia and Ghana, are democratic states located on four different continents, and have a long history of mining despite differences in their economies. In 2015, Sweden, Australia and Chile were classified as high-income countries while Ghana was classified as a lower middle-income country[21]. Figure 2-27 compares the four countries on the basis of real GDP

[21] Source: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups. Accessed on 03 April 2019

per capita, which in this case is used as a proxy for Gross National Income per capita, a measure used by the World Bank for classification of countries' economic strengths and citizens' standard of living.

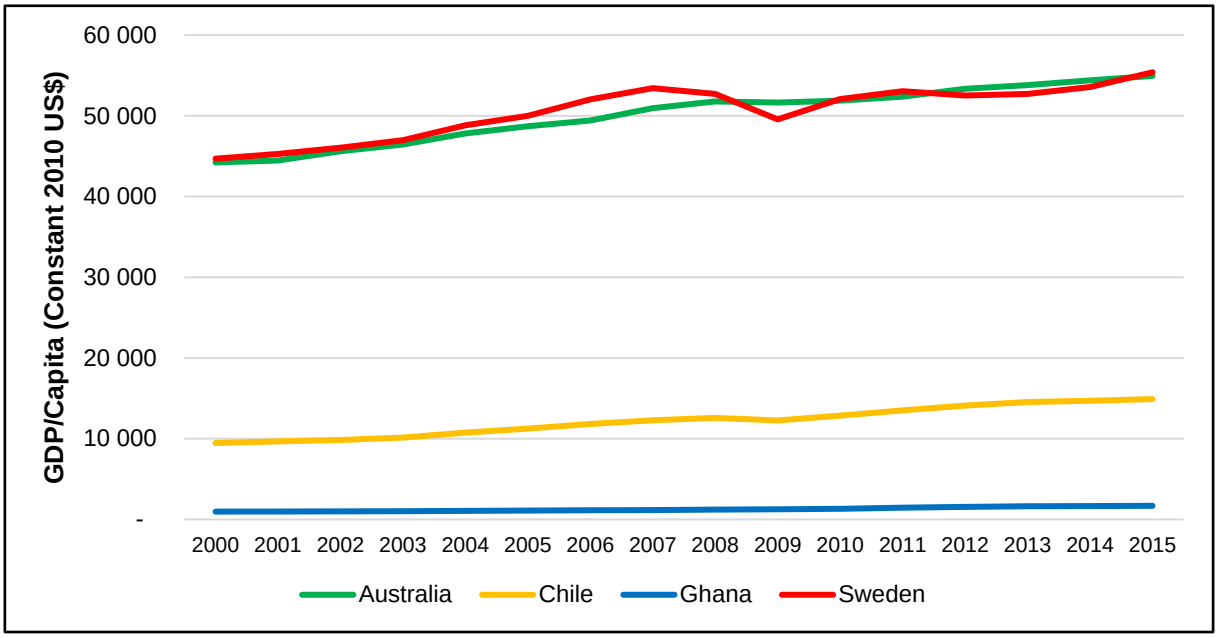


Figure 2-27: Comparison GDP per capital of Australia, Chile, Ghana and Sweden from 2000 to 2015 (Data sourced from The World Bank, 2018).

In the period from 2000 to 2015, Ghana had the highest average GDP per capita growth rate of 3.8%, followed by Chile with 3.1% and Australia and Sweden with 1.5% each. The growth rates of Ghana and Chile over the period of 2000 to 2015 resulted in the transition of both countries from low income to lower middle income and upper middle income to high income status, respectively. Australia and Sweden remained high income countries throughout the 2000 to 2015 period.

The contributions of mining to the GDPs of the four countries vary. On the lower side is Sweden with 0.87% contribution to GDP in 2010, mining in Ghana contributed 7.6% in 2015, in Australia it was 9% in 2016 and in Chile it was 15% in 2010. In Chile mining

accounted for 66% of the total exports in 2010, in Australia mining accounted for 50% of the total exports in 2016, in Ghana the mining accounted for 37% of the total exports in 2013 and in Sweden mining accounted for 10% of the total exports in 2013. Chile, Ghana and Australia can be described as mineral dependent countries, while Sweden can be described as a manufacturing intensive country because manufactured goods accounted for over 75% of the total exports in 2013.

The four countries are endowed with several minerals, but there is one primary mineral in each country that contributes significantly to the economy. In Chile copper is the primary mineral, in Sweden and Australia it is iron ore and in Ghana it is gold. Chile and Sweden have state owned companies (Coldelco and LKAB) that successfully operate several mines in their respective countries alongside private mining companies. Coldelco primarily mines copper and LKAB primarily mines iron ore. The mining industry in Australia and Ghana relies on private companies, with the latter having reversed the 1980s' direct state participation in mineral exploitation. The State in Ghana enjoys a free carry stake in mines ranging from 0% to 20%.

The two state owned companies in Chile and Sweden play a crucial role of entrenching mining backward linkages. In Sweden, historically LKAB has used its dominant position in the country's mining industry to support mining backward linkages. This was achieved through partnerships with local (and regional) OEMs to develop equipment and test equipment in real-life mining environment. This relationship was also extended to services companies. Private mining companies in Sweden also have long standing partnerships with local OEM and services companies in the backward linkages. Mining companies, OEMs, services companies and other agents in the backward linkages in

Sweden are generally referred to as mining cluster, an indication of a strong symbiotic relationship within the cluster.

Codelco in Chile has also actively assisted local companies to develop home-grown technologies and supported their growth through preferential procurement. One of the programmes it has used in this regard is the World Class Suppliers Program that was started by BHP Billiton in 2010. Historically, Chile was an importer of mining technology, but this has started shifting since 2000. By 2013 it was estimated that there were 4 000 services companies that employed 67.7% workers in Chilean mines, thanks to a number of policy interventions and capacity building programmes as summarized in Figure 2-9.

Codelco and LKAB are testimonies of how a professionally managed state-owned mining company can be used to support mining backward linkages. Chile and Ghana nationalised mining companies in the 1970s and reprivatised them in the 1980s. However, Chile decided to retain Codelco while opening its mining industry to private investors. Ghana opted to have a minority free carry stake in mining companies, and this has put the state in a position that it cannot directly influence procurement decisions on the mines.

Ghanaian mines principally rely on imports and that severely undermines local backward linkages. The government of Ghana has attempted to bolster local backward linkages through the introduction of L.I. 2173 in 2012. By 2016, the L.I. 2173 had limited success in supporting local manufacturing. In fact, some of the local companies have used a loophole in the regulations and were selling imported goods to local mines.

Australia does not have a mining state owned company but has managed to develop formidable mining equipment, technology and services (METS) companies which have grown over the years to a point where in 2012 contributed 6.5% to the country's GDP. The growth of METS in Australia has been underpinned by its complex relationship with mining companies, research institutions and universities. This foundation has been solidified to the extent that METS flourished during the mining investment boom from 2000 to 2013 in Australia.

Lessons coming out of case studies of the four countries above, can be summarised as follows:

- Collaboration between mining and supplier companies is crucial in entrenching local backward linkages. There must be a concerted effort to support locally developed technologies as is the case in Sweden and recently in Chile. This collaboration must be supported by research institutions and universities as is the case in Australia.

- A country must have a significant mineral endowment that is exploited by agents with a developmental mandate as is the case with Chile and Sweden. In the absence of such agents, there must be appropriate policies and legal instruments to foster development of local supplier companies. The L.I. 2173 in Ghana is an example of such legal instruments geared towards increasing the value of local content in goods and services procured by local mines. While local content is not clearly defined in the L.I. 2173, it is nonetheless a step in the right direction for Ghana.

- Local production factors must be well equipped to take advantage of growth opportunities locally. This is demonstrated by growth in the size of METS in Australia that coincided with mining investment boom and Sweden whose OEMs have significant global market share. The METS are supported by historical collaboration between mining companies, METS, research institutions and universities as is the case in Sweden. In Ghana the introduction of L.I. 2173 was met with muted success due to lack of adequate local manufacturing capacity. In fact, by 2016, the biggest beneficiaries of the introduction of L.I. 2173 were importers.

2.5. Summary

The purpose of this chapter was to provide a perspective of the evolution of the resource linkage theory and to review manifestation of backward linkages (a component of production linkages) through case studies. This was underpinned by a paradigm that mining technology can create more employment opportunities outside the mining industry than in the industry itself. The driver behind these employment opportunities are five resource linkage domains, namely production, consumption, fiscal, spatial and lateral migration linkages. The resource linkage theory emerged in the late 1950s after a robust discussion about whether developing countries should follow a balanced or unbalanced growth model in order to escape economic stagnation that engulfed many of developing countries post World War II.

The implicit lesson emerging from this chapter is that countries must guard against the enclave nature of mining if domestic employment opportunities are to be created. Mineral resources can be used as leverage for economic growth provided there are

measures to harness economic linkages. For example, production linkages, in particular backward linkages, can be used to kick-start or invigorate industrial activities. In this case, Marshallian externalities within domestic clusters around mining companies can be harnessed until side-stream linkages are induced within the backward linkage. Further enhancement, subject to organisational learning, assimilation, and enterprise interaction, can lead to the envelope bursting into lateral migration. Simultaneously, forward linkages can be extended along the mineral value chain as shown in Figure 2-3, with each node along the mineral value chain being capable of developing into a base industry with its own linkages.

In order to benefit economically from resources, governments can capture resource rents and give rise to fiscal linkages. There are two types of fiscal linkages, namely direct and indirect linkages. The former refers to linkages associated with taxation of exports of enclaved productive activities and the latter refer to taxation of imports into the production of staple products. While these taxes are expected to be used by the state for a variety of social programmes, investments into public goods that lead to better exploitation of resources and increased economic activity in general have the potential to give a better return on captured rents. Examples of such public goods would be a provision of better and inclusive education and health systems, power and water reticulations, and rail, road and communication networks to support industries.

Lastly, a good foundation in the form of a strong and important base industry operating within a generally good business environment has the potential to induce lateral migration or technology spill-over effects as the economy matures and move into knowledge based sectors. Lateral migration can be achieved through organic growth

where internal innovation and organisational learning are key ingredients. On the other hand, it can be achieved through acquisition of other companies or their technology.

The linkage domains are good examples of benefits acrued to a resource endowed country when the effects of the resource curse have been avoided. Fundamentally backward and forward linkages are the best domains to focus at if the extends of resource benefits acrued to a country are to be studied. This being the case and in line with objectives of this thesis, case studies were used to understand the manifestation of backward linkages in Chile, Sweden, Australia, and Ghana.

The four countries were chosen firstly, because of their long history of mining and secondly, because of their geographical locations, with Chile being in South America, Sweden being in Europe, Australia being in Australia and Oceania and Ghana being in Africa. By 2015, Sweden, Australia and Chile were high income countries and Ghana was a lower middle-income country. Mining in Chile, Australia and Ghana in the years between 2010 and 2016 accounted for more than 25% of the total exports and therefore during this period the three countries were classified as mining dependent. In Sweden, mining in 2013 accounted for approximately 10% of the total exports, with manufactured goods accounting for more than 75% of the total exports, making Sweden a manufacturing intensive country.

Chile belongs to the Latin Americas region and is an important source of copper, accounting for approximately 40% share of the global copper export. Mining takes place largely in the Antofagasta region. Sweden is an important mining jurisdiction in Europe accounting for approximately 90% of iron ore, 32% of lead, and 23.5% of zinc in the total EU production in the years prior to 2015. Perhaps the most important

country as far as the iron ore production and export are concerned, is Australia which is also endowed with coal, copper, gold and bauxite. Ghana has for many years been one of the important sources of gold in Africa. Gold in Ghana accounts for over 90% of the mining revenue. In 2011, Ghana started producing oil and by 2017 the oil industry was the third exporter after mining and cocoa.

All four countries have, with varying degrees, established mining backward linkages. Sweden and Australia have by far entrenched backward linkages, with Sweden having few, but internationally competitive mining suppliers of goods and services. Australia has relatively more mining suppliers, particularly mining services. Some of the mining suppliers from Australia are also internationally competitive. The success of Sweden and Australia, among others, is due to collaboration between various stakeholders such as mining companies, suppliers and research institutions.

Chile has a large number of mining suppliers well over 4 000 of them, thanks to the outsourcing strategy of Chilean mines. However, a majority of mining suppliers (particularly mining services suppliers) are too small to be competitive internationally. Approximately 54.2% of mining services suppliers in Chile are in the Santiago Metropolitan Region, 25.8% are in the Antofagasta Region and the balance is spread out among other regions. Chile was historically an importer of mining inputs, but lately due to initiatives such as World Class Suppliers Program by BHP Billiton and Codelco, well established mining suppliers are starting to emerge.

Mining in Ghana historically has been importers of goods and services. The government of Ghana introduced L.I. 2173 in 2012 with the primary objective of increasing local content of mining inputs into the Ghanaian mines. By 2016 the L.I.

2173 had muted success, perhaps due to lack of clarity on what constitutes local content. While L.I. 2173 has managed to give local manufacturing companies an opportunity to secure contracts in local mines, the bulk of the opportunity went to local importers whose mining procurement value increased by 147.3% between 2014 and 2016 compared to 44.1% of local goods and services providers over the same period.

The four case studies in this chapter were used to gain an understanding of mining linkages in international mining jurisdictions. South Africa is one of the mining jurisdictions with a long history of entrenched mining backward linkages and to this effect, Chapter 3 gives an overview of mining linkages in South Africa.

3. An overview of the South African mining backward linkage environment

3.1. Introduction

South Africa is one of the countries on the African continent that has a long history of a well-established mining industry. This is underpinned by the country's mineral endowment. At the inception of organised mining in South Africa in the 1870s and 1880s, diamond and gold mining were the bedrock of the industry, but in recent times coal and platinum group minerals have taken over the baton. Mining historically was generally regarded as the key building block of the economy and an important foreign-exchange reserve earner.

Over the years the mining industry has managed to establish economic linkages with other sectors of the economy particularly in the processes that add value to mined products (beneficiation) and manufacturing of products that are used by mines in the processing of mining and treatment of ores. Nonetheless there has been unhappiness largely with the level of beneficiation and to some extent the import component of mining inputs into the local mines. In this chapter, the link between mining and the rest of the economy will be explored.

3.2. General overview of the South African economy

South Africa is a constitutional democracy with one of the most diverse economy in Africa. It was ranked the second biggest economy in Africa in 2015 after Nigeria and it had a GDP per capita of US$11,035, one of the highest among the African countries

(Chigozie, n.d.). South Africa has nine provinces and over 60% of its value-add products comes from three provinces namely Gauteng, KwaZulu Natal and Western Cape and collectively these provinces are a home to 54% of the population (Statistics South Africa, 2016a and Statistics South Africa, 2017).

Statistics South Africa (2016a) estimated the country's population at 55.6 million in 2016, with 51% females and 49% males. In the same year, the level of education amongst its populace was better compared to 1994. For example, in 1996 people without schooling who were older than 25 years were 9.3% of the population and that number dropped to 4.1% in 2016. On the other hand, the portion of the population with tertiary qualifications (bachelor, masters, and doctorate degrees) increased from 1% in 1996 to 2.2% in 2016. While this proportion is small compared to countries such as Australia (see Figure 2-17), it is nonetheless a welcomed growth that should support and bolster economic growth going forward.

The economy of South Africa was largely agrarian before the advent of large-scale mining in the latter half of the 1800s. After the discovery of large deposits of diamonds, coal and gold, mining gave rise to other sub-sectors of the industrial sector such as manufacturing (heavy and light engineering, chemicals), electricity generation and construction to some extent as input into mining (Fedderke and Wollnik, 2007). While mining was largely in private hands (largely English speaking foreigners or naturalised persons), the South African government established State owned enterprises in manufacturing, electricity, communication and transport sectors such as ISCOR, ARMSCOR, ESKOM, TELKOM, and Spoornet to drive industrialisation under its import substitution policy (Leeuw, 2012).

To this day, mining and manufacturing continues to occupy a special place in the economy of South Africa, but its contribution to the GDP has been declining at the expense of services super sector (wholesale, transport, finance, and personal service) particularly after 1994. For example, the contribution of mining and manufacturing to the GDP in 2010 constant prices were 15% and 14%, respectively in 1993, but dropped to 8% and 12%, respectively in 2015 (Statistics South Africa, 2016b). Figure 3-1 shows contribution of different economic sectors to the South African GDP in 2015 in nominal terms.

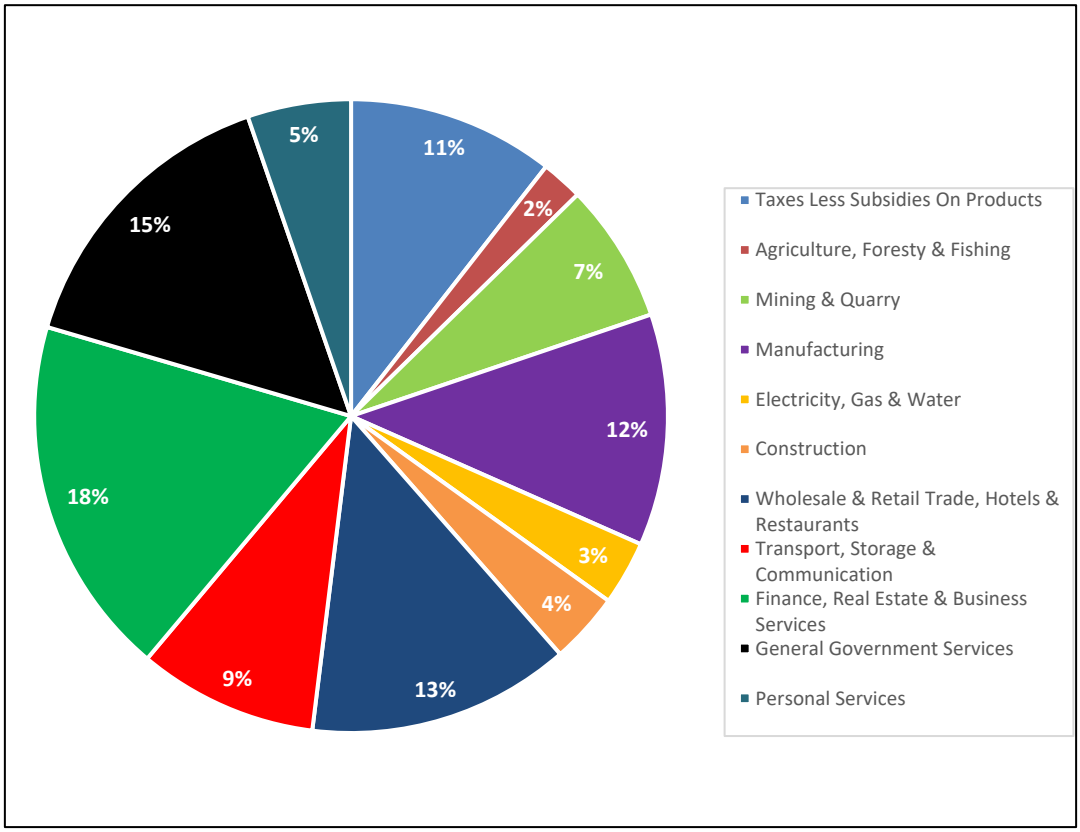


Figure 3-1: Contribution to South African GDP in constant 2010 prices in the broad sectors of the economy (Statistics South Africa, 2016).

In Figure 3-1, it can be observed that the biggest contribution to the GDP in 2015 was from a sector encompassing finance, real estate, and business services, followed by

general government services and wholesale, retail trade, hotels and restaurants. Apart from general government services, all these sectors fall under the services super sector, implying that the South African economy has over the years transformed from agriculture in the greater part of the 1800s, mining in the late 1800s and manufacturing in the mid-1900s to services in recent times.

The transformation into services dominated economy can be observed better in Figure 3-2, when taxes and general government services are excluded from the data and sectors are constituted to reflect super sectors namely agriculture super sector (agriculture, forestry, and fishing), industry super sector (mining, quarrying, manufacturing, electricity, gas, water, and construction), and services super sector (wholesale, retail trade, hotels, restaurants, transport, storage, communication, finance, real estate, business services, and personal services). It can be noticed that the contribution of services to the GDP has been growing consistently from 1993 to 2015, while industry has been declining. The contribution of agriculture has been nearly constant over the same period.

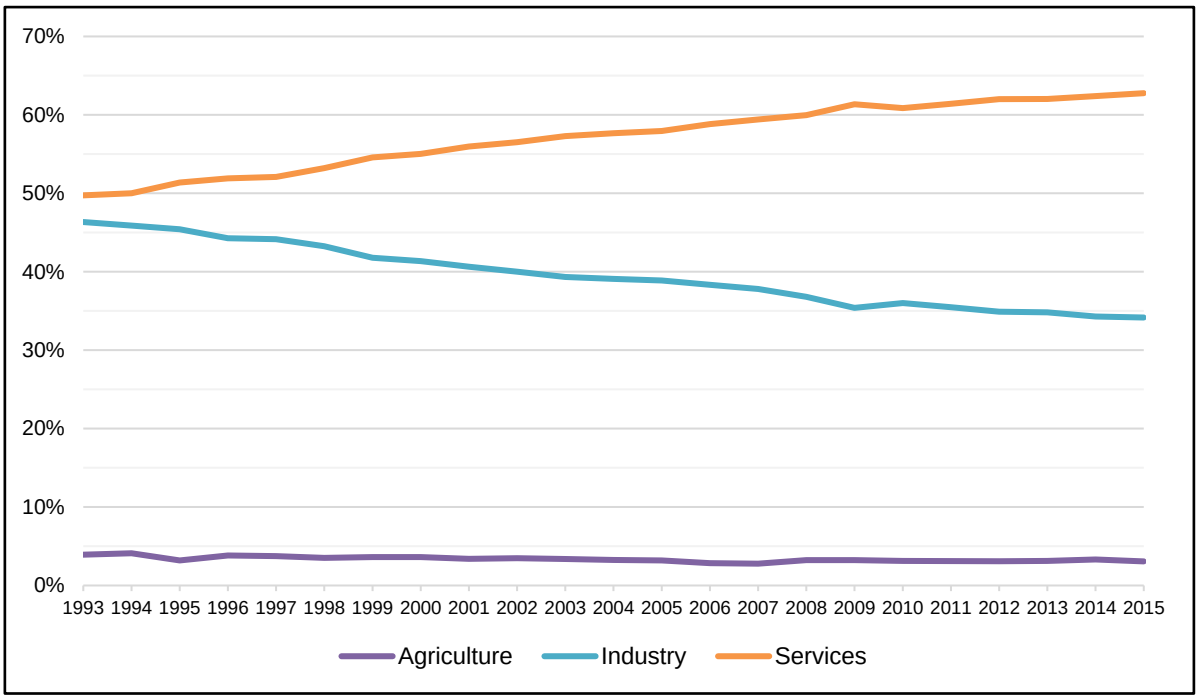


Figure 3-2: Percentage contribution of the three economic super sectors in South Africa to 2015 GDP based on current prices (Statistics South Africa, 2016).

Further analysis of the economic performance of the various sectors in South Africa particularly when growth is taken into account after 2010, reveals in Figure 3-3 that sectors under services grew continuously from 2010 to 2015, while those under industry, apart from construction, did not have a consistent upward trajectory. For example, the contribution to GDP growth of mining was negative between 2010 and 2012, improved in 2013, deteriorated marginally in 2014, and improved again in 2015. The contribution to GDP growth of manufacturing grew between 2010 and 2013, plateaued between 2013 and 2014, and declined slightly in 2015.

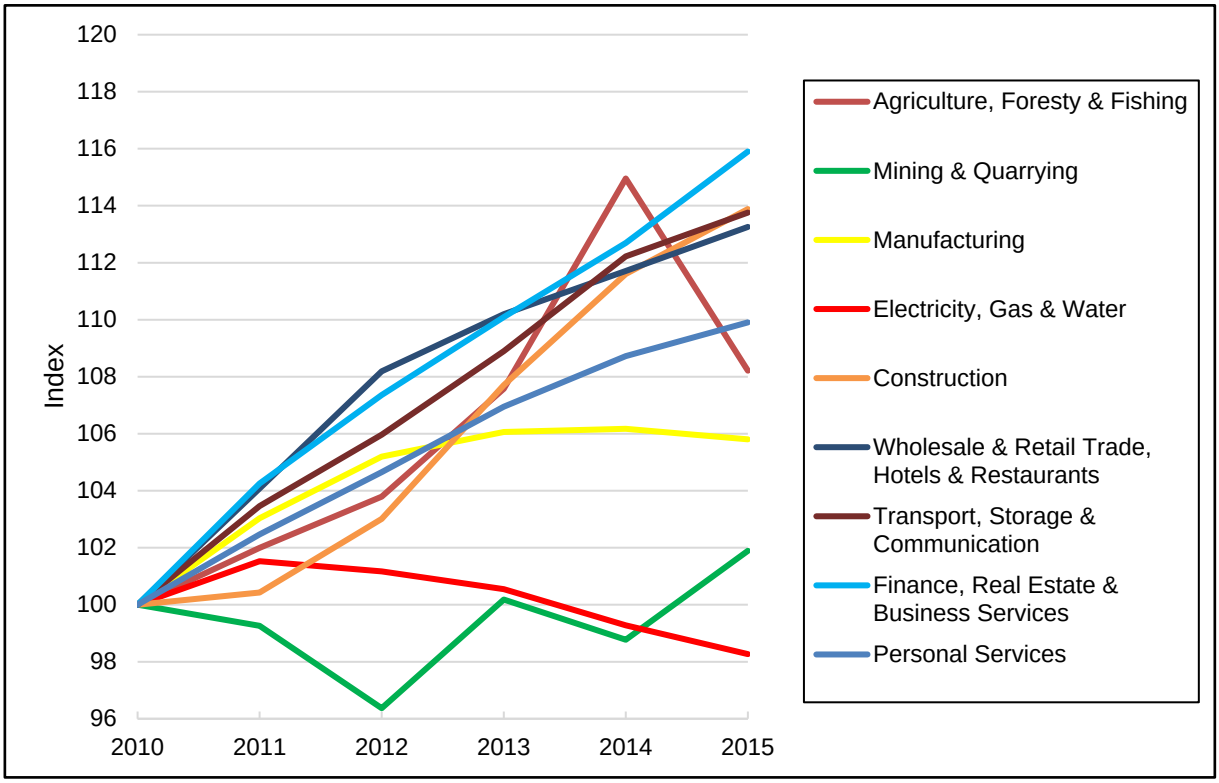


Figure 3-3: The index of the contribution to GDP growth of various sectors of the South African economy from 2010 to 2015 based on 2010 constant prices (Statistics South Africa, 2016).

If contribution of various sectors to the GDP of the nine provinces of South Africa is considered, it will be noticed in Figure 3-4 that they mirror the national picture, that is, services are more prominent than industry and agriculture. When focusing on sectors that make up industry, it will be noticed that contribution of mining is high in the Northwest, Limpopo, Northern Cape, Mpumalanga, and Free State provinces. Conversely, mining's contribution is insignificant in the Eastern Cape and Western Cape provinces. It can also be observed that where mining is strong, manufacturing is crowded out, as is the case in North West, Limpopo, and Northern Cape provinces and to some extent in Mpumalanga and Free State provinces, a typical crowding out effect of mining observed by Davis and Tilton (2002).

The same arguments can be extended to services, that is, the contribution of services to the provincial GDP is inversely proportional to the contribution of mining. The crowding out effect can have a material impact on the regional (intra-provincial) mining linkages, i.e. mines in strong mining provinces link better with manufacturing firms in provinces such as Gauteng and Western Cape than firms within their own provinces. Stated differently, mines have a tendency of inducing higher employment multipliers in other provinces than within their provinces.

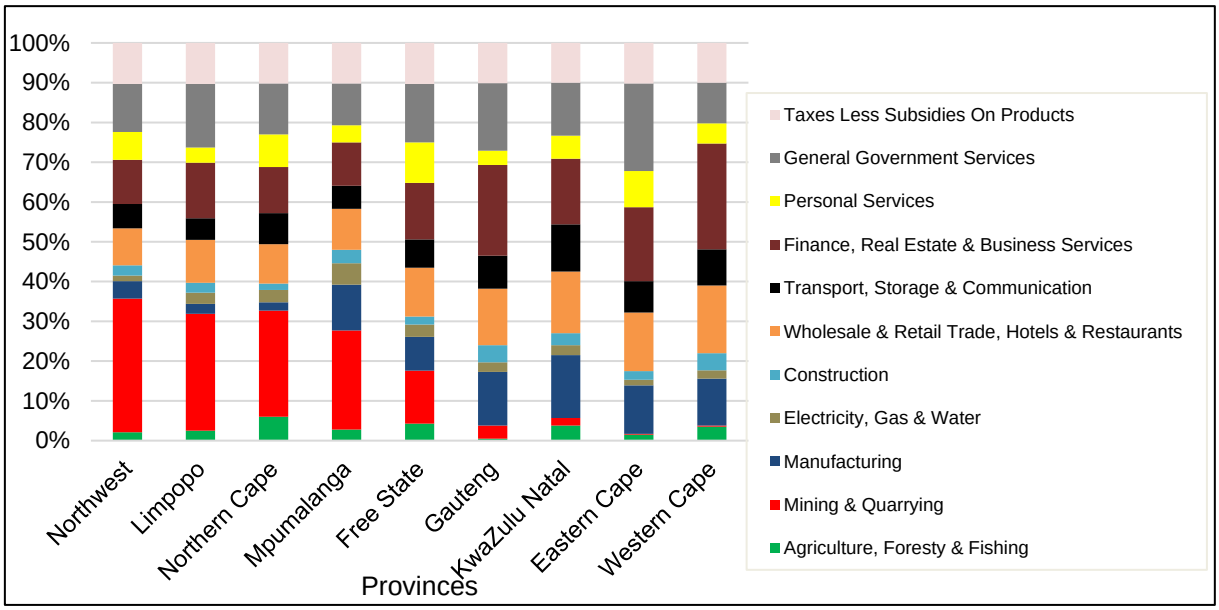


Figure 3-4: Contribution of various sectors to the provincial GDP in South Africa in 2017 (Statistics South Africa, 2017a).

3.3. Historical overview of the South African mining industry

The recorded history of mining in the southern part of Africa date as far back as 1000 or more years ago in the Mapungubwe and Phalaborwa areas (see Figure 3-5), where inhabitants traded in gold and copper with Arabs, Orientals and later with the Portuguese (Letcher, 1936 and Leeuw, 2012). Much later in the 1600s the Dutch

established a colony in the southern tip of South Africa (now called City of Cape Town) and started mining copper in 1865 at Koperberg near Springbok town. In 1846, the British took over copper mining at Koperberg and went on to discover a small coalfield near Stormberg Mountains in 1864, and later bigger coalfields near the towns of Bethal and Vereeniging (Botha, 1934 and Pogue, 2006).

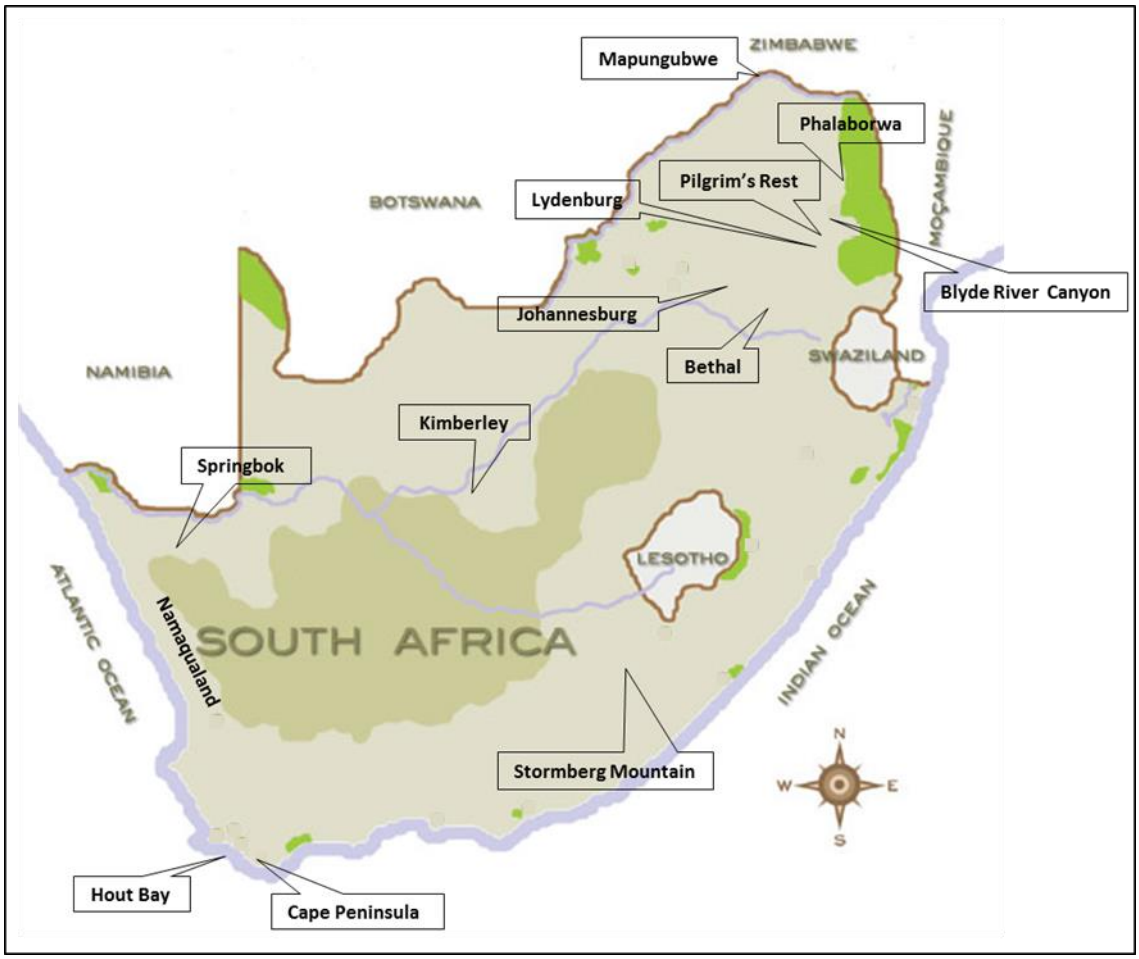


Figure 3-5: Early history of mining in South Africa (Leeuw, 2012)

The real interest in South Africa as a mining destination started in 1870 after the discovery of diamonds near Kimberley. The Kimberley kimberlite pipes were large enough to attract investors and mining entrepreneurs from Europe and the USA. When gold in the Witwatersrand Basin was discovered, mining barons of Kimberley invested

their fortunes in the development of mines in this newly discovered gold deposit. With the consolidation and reorganisation of mining operations in the Witwatersrand, the concept of Mining Houses was formed. These were basically mining corporations that financed and provided technical assistance and leadership to mines within their portfolios (Mawby, 2000).

As mining in the Witwatersrand Basin grew, the need for an industry representative body arose. To this effect, the Chamber of Mines of South Africa (the Chamber) was established in 1889. Besides being a representative of mining companies and lobby agent, the Chamber over the years offered various services to its affiliates such as Corporate Services; Health Care Services; Recruitment Services (The Employment Bureau of Africa or TEBA); External Relations; Chamber of Mines Research Organisation (COMRO); Safety and Technical Services; and Environmental Management Services. COMRO was officially established in 1965 and was an entity responsible for research and development particularly for the gold mines. It was notably instrumental for technologies such as hydropower, emulsion hydraulic (EH; 5% oil and 95% water) and HH (100% water) for portable hand-held drill machines, underground support systems, and stope/panel designs (Chamber of Mines of South Africa, 1982 and Chamber of Mines of South Africa, 1990).

Since the discovery of kimberlite pipes in the Northern Cape Province, coalfields in Free State, Mpumalanga and KwaZulu Natal, and the Witwatersrand Basin that hosts deposits of gold, uranium, silver, pyrite and osmiridium, there have been other geological structures discovered as well that host other minerals. For example, the Bushveld Igneous Complex hosts deposits of platinum group minerals (PGM), chromium, vanadium, titanium, nickel, cobalt, copper, fluorspar and andalusite among

others, whereas the Palaborwa Igneous Complex hosts deposits of copper, phosphate, titanium, vermiculite, feldspar and zirconium. There are also deposits of heavy minerals along the eastern coast and alluvial diamonds along the western coast (Department of Mineral Resources, 2016).

Driven by the endowment of minerals, the mining industry over the years has grown and contributed significantly to the economy of South Africa. In 2014, there were 1796 operational mines and quarries in South Africa, producing approximately 53 different minerals across the nine provinces. These mines and quarries collectively employed close to half a million people or 2.5% of the working population in 2014. Figure 3-6 shows the distribution of employment in the mining industry across different mining sub-industries in 2014 (Department of Mineral Resources, 2016).

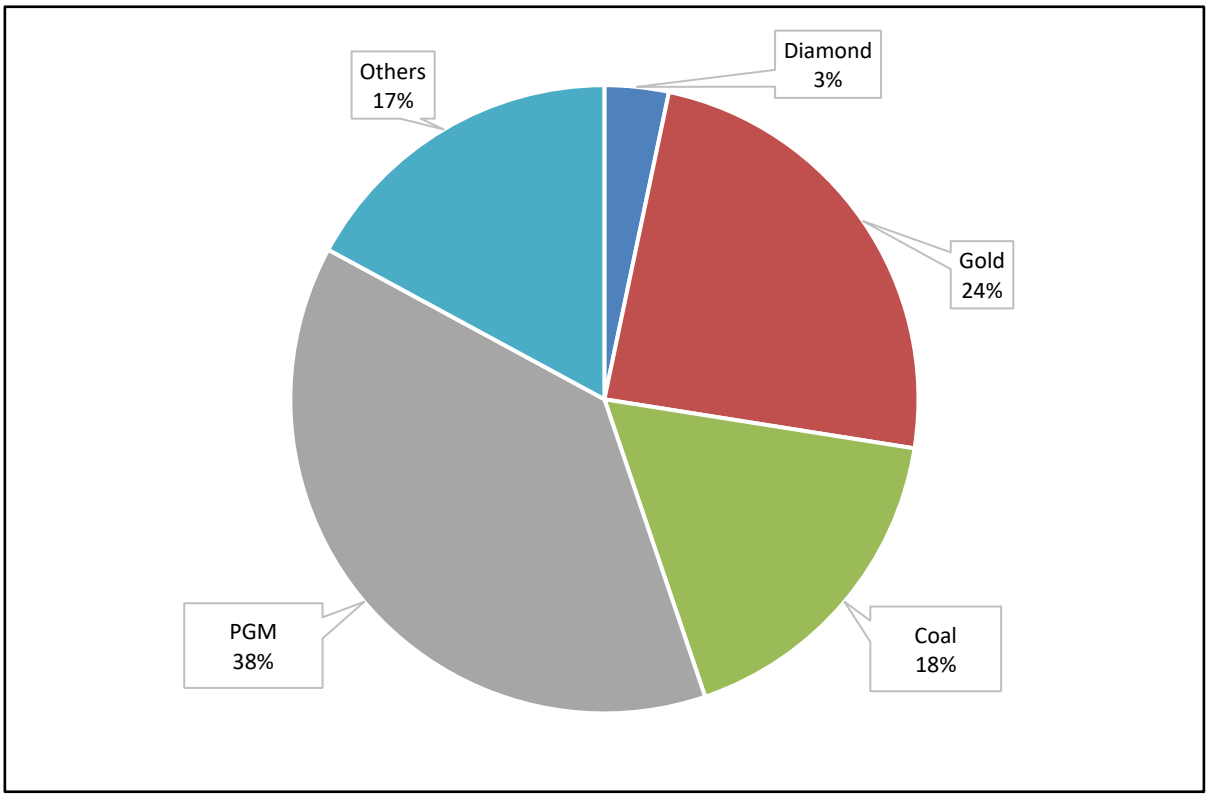


Figure 3-6: Employment distribution across different mining sub-industries in South Africa in 2014 (Department of Mineral Resources, 2016).

While there has been limited exploration and investor apathy in the past 10 years leading to 2014 in South Africa due to policy uncertainty, there was however appreciable levels of investment into new and expansion mining projects amounting to R362.6 billion in 2014. Figure 3-7 shows the distribution of capital expenditure in 2014 across various sub-industries of the mining industry. This residual interest in the South African mining in times when there were political and policy uncertainties and general global subdued mineral prices, pointed to potential continuity of mining linkages (Department of Mineral Resources, 2016).

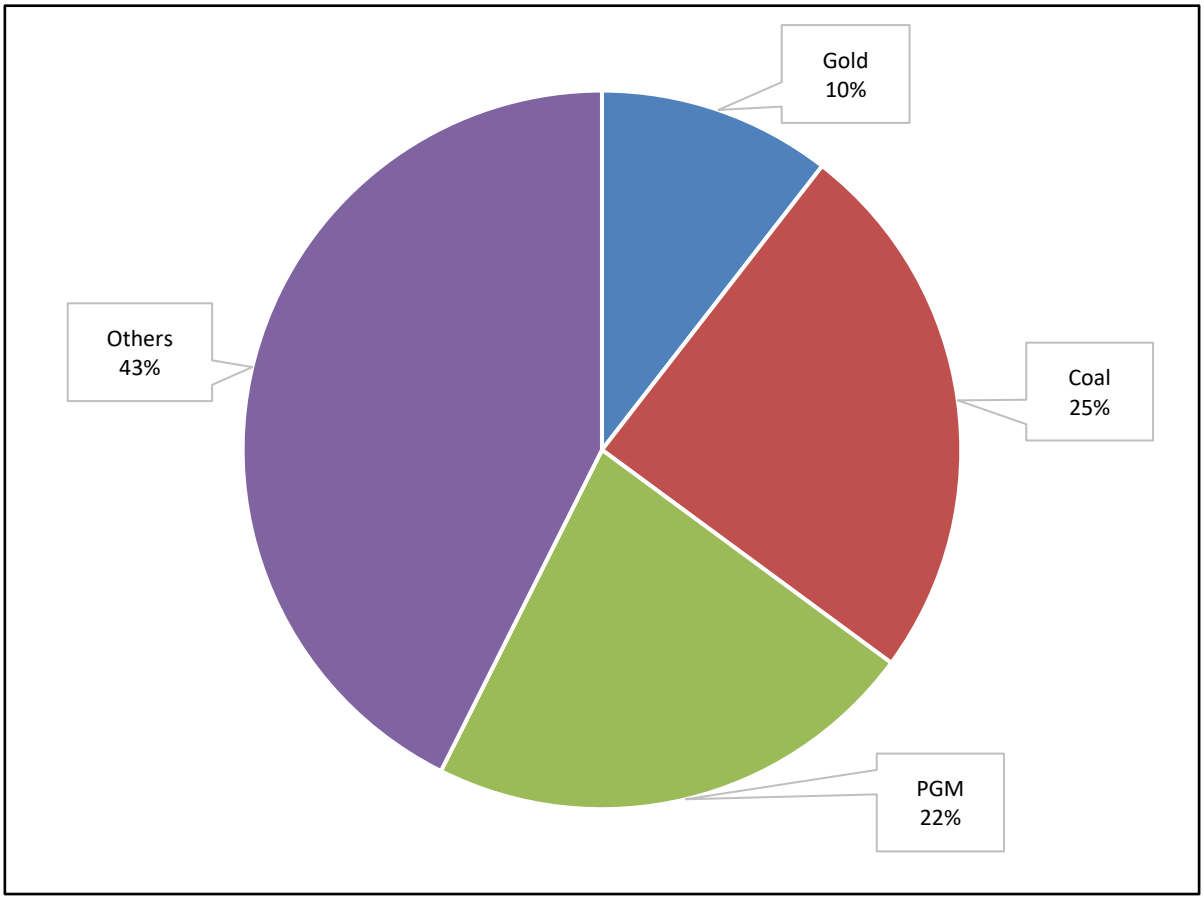


Figure 3-7: Capital expenditure distribution across different mining sub-industries in South Africa in 2014 (Department of Mineral Resources, 2016).

3.4. Mining backward linkages in South Africa – a historical perspective

Historically, mining in South Africa has had strong linkages with the rest of economy to the extent that it led to the formation of other industries. According to Hirschman (1958), linkages emanating from the base industry are considered strong if the base industry induces the formation of other local industries. The economic effects become pronounced if the formation occurs within clusters. This feat was historically achieved by the South African mining industry in the twentieth century.

For example, in 1903, the mining industry under the leadership of the Chamber sought to increase underground production. The solution to this undertaking was to increase the number of holes drilled and blasted per working shift. This was to be achieved through the introduction of lightweight hand-held drill machines equipped with a central hole along its drill steel for pneumatic or hydraulic flushing. However, the obstacle was that the most suitable machine was manufactured under patent which made them too expensive for many operations in the Witwatersrand Basin to procure (Pogue, 2006).

The other reason that put pressure on mines to find an alternative to the old way of drilling blast holes, i.e. the chisel and hammer method which at best produced one metre blast hole per shift per two workers (driller and his assistant), was the shortage of underground labourers caused by wars. The first was the Anglo-Boer war from 1899 to 1902 and the second was World War I from 1914 to 1918. While Africans, who were used as underground labourers in the mines, were not directly fighting in the wars, were taken from the mines and forced to do menial jobs in support of soldiers of European origin (ibid).

The breakthrough came in 1913 when the patent of the aforementioned drilling machine expired, leading to their low cost of production and hence low cost of acquisition. Despite their obvious superior production output over the manual chisel and hammer drilling, it took close to 30 years from 1903 to 1933 for these machines to get full acceptance in the gold mining sub-industry as shown in Figure 3-8 (Pogue, 2006). This machine remained the premier stoping equipment from 1933 to 1965 when COMRO was established.

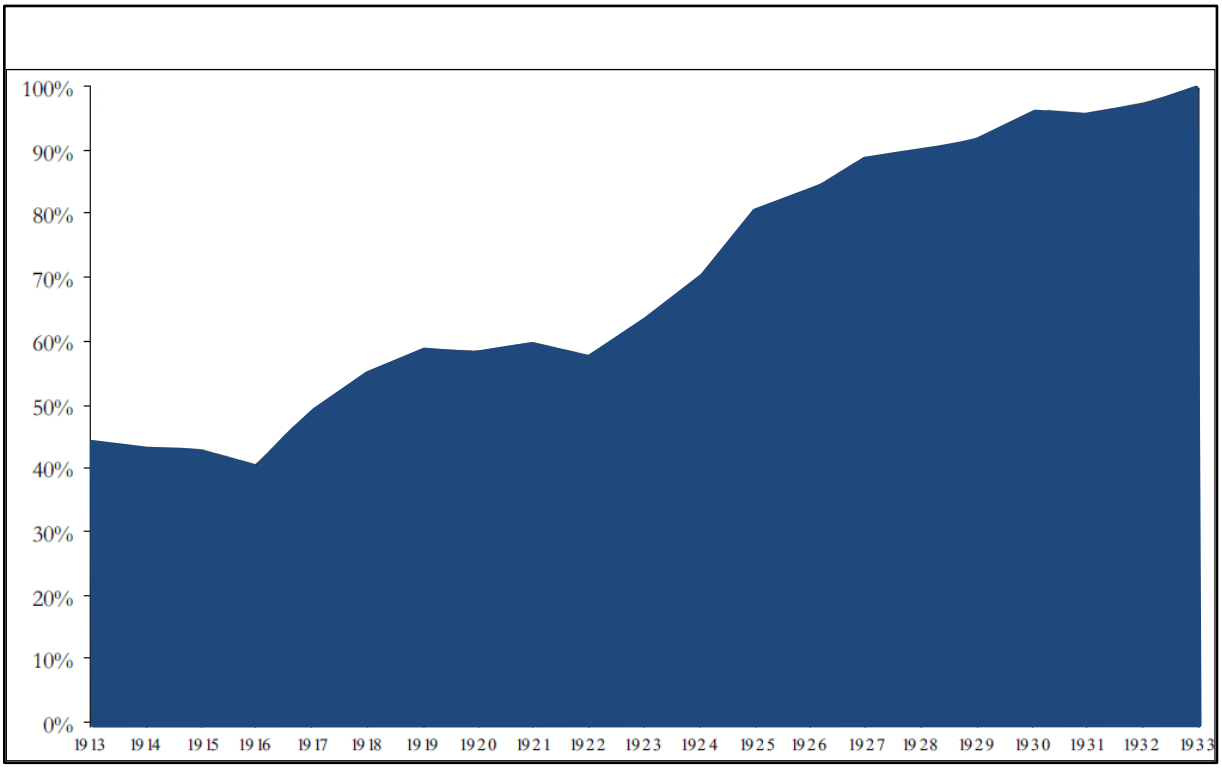


Figure 3-8: Penetration rate of portable rock-drills in the Witwatersrand Basin between 1913 and 1933 (Pogue, 2006).

COMRO partnered with companies such as Ingersoll-Rand, Novatek and Sulzer in the development of the new generation of rock drilling tools that were to use EH and HH technologies. It was not then surprising when these companies became premier suppliers of these machines to the hard rock gold mines and platinum mines in South

Africa. The offshoot of HH technology was hydropower technology for deep and hot underground mines. Hydropower technology is basically chilled water supplied underground under high pressure to power mining equipment and to cool down the working space. From this technology, literally out of the COMRO laboratories, a company called Hydropower Equipment (HPE) emerged to manufacture and supply underground hydropower mining equipment such as drill rigs and loading equipment.

Another example of the historical mining linkages is that of explosives in South Africa. The Zuid Afrikaansche Fabrieken voor Ontplofbare Stoffen Beperk or 'The Dynamite Company' was formed in 1895 at Modderfontein by Alfred Nobel after the intervention of the then President of Transvaal, Paul Kruger. The intervention of President Paul Kruger was due to difficult condition miners were encountering in the Witwatersrand Basin. After mining exploitation in the Witwatersrand Basin had proceeded beyond the easy to excavate oxidised ground into the hard to excavate virgin ground, production yields dropped, and several operations were closed. The solution was to manufacture explosives locally and sell them to miners at affordable prices, hence the establishment of the dynamite factory at Modderfontein (Leeuw, 2012).

De Beers also established its own dynamite factory at Somerset West in the Northern Cape Province in 1903. In 1908 the Dynamite Company built a second plant in Umbogintwini in Kwazulu Natal. Collectively, the Modderfontein, Umbogintwini, and Somerset West factories made South Africa the biggest manufacturer and consumer of dynamite then. The three dynamite factories merged in 1924 to form African Explosives & Industry, a De Beers subsidiary then. The African Explosives & Industry grew organically to become an explosives and chemical factory selling to other markets outside the mining industry. The company changed its name to African Explosives &

Chemical Industry to reflect its product offering and was listed on the Johannesburg Stock Exchange in 1966. Ten years later it changed its name to AECI Limited and in the early 1990s AECI Explosives Limited, a specialised subsidiary of AECI, was formed. The organic growth of the explosive business under the newly formed subsidiary continued throughout the 1990s and in 1999 it changed its name to African Explosives Limited (AEL). Lately AEL has expanded its market beyond the borders of South Africa (African Explosives Limited, 2017).

In a study about mining capital equipment in South Africa where a database of 678 companies was used, Kaplan (2011) found that 67% of companies were local and 33% were foreign, with foreign companies being described as specialist consultants or OEMs. Although not substantiated, Lydall (2009; p. 114) was of the opinion that “a 200 000 ton per month platinum mine can involve up to 100 000 part assemblies and the number of active suppliers in anyone PGM operation can range from 2000 to 5000 firms”. Nonetheless, Lydall use a database of 220 companies in the case study titled “Backward linkage development in the South African PGM industry”. Both research works of Kaplan and Lydall indicated that mining in South Africa over the years has manage to induce a large number of mining supplier companies that supplies goods and services to local mines.

3.5. Current Mining Supplier Environment in South Africa

If one analyses the South African input-output table of 2015 published by OECD.Stat (2018), important mining input sectors become apparent. In this particular edition, there were 36 economic sectors and important input sectors with the annual value greater

than US$100.00, either into the non-energy or energy minerals sub-industries, are shown in Table 3-1.

Table 3-1: Important input sectors into the South African non-energy and energy minerals sub-industries in 2015 (OECD.Stat, 2018).

Sector	Non-energy Minerals (US$ millions)	Energy Minerals (US$ millions)
Contract mining*	3 234.9	907.7
Utilities	1 663.6	556.9
Finance and insurance	1 480.6	181.9
Wholesale and engineering services	1 295.8	373.6
Chemicals	1 214.2	280.9
Transportation and storage	931.5	342.1
Machinery and equipment n.e.c.	697.3	217.6
Petroleum products	545.0	176.0
Consultancy	506.5	323.2
Other business sector services	413.0	289.8
Fabricated metals	375.5	105.5
Rubber and plastics	263.5	81.9
Motor vehicles, trailers and semi-trailers	258.1	18.9
Electrical equipment	189.9	49.9
Textiles, wearing apparel, leather and related products	170.0	22.5
Construction	34.1	129.2

*Aggregated value of contract mining activities.

In Table 3-1, the important input sectors that fall within the scope of this thesis in terms of value are contract mining; wholesale and engineering services; chemicals; transportation and storage; machinery and equipment (not elsewhere classified [n.e.c.]); petroleum products; consultancy; fabricated metals; rubber and plastics; motor vehicles, trailers and semi-trailers; electrical equipment; and textiles, wearing apparel, leather and related products. In Table 3-1, if Utilities, Finance and Insurance, and Transportation and Storage sectors are ignored, the combined value of the remaining sectors can be taken as largely the indication of the value (excluding labour cost) of the mining production backward linkage envelope in South Africa.

3.5.1. Mining Contractors

By 2019 there were a number of contract mining companies providing services to surface and underground mines in South Africa. The sizes of these companies range from those with several hundred employees per site to less than 20 employees per site. The big and well-established contract mining companies in South Africa include Concor Mining Services (a platform under Concor umbrella), Aveng Grinaker-LTA, Aveng Moolmans, Murray & Roberts Cementation, Stefanutti Stocks Mining Services. The established medium sized contract mining companies in South Africa with over 20 years of service include Benhaus Mining, Benicon Opencast Mining, Andru Mining, Atlantis Mining, Newrak Mining, Provest Group, Pretorius Group of Companies, Redpath South Africa, and Trollope Mining Services. The emerging contract mining companies in South Africa include Basadi Underground Contractors, Legare Mining Services, MCS Mining, Platchro Mining Services, Sekgwa Mining Services, STA Coal Mining Company, Supa-Gold Corporation, Tripple M Mining, Tshiamo Resources and Lefatsi Mineral Resources.

The services provided by mining contractors include shaft sinking, mine development and construction, haul road construction and maintenance, surface drilling and blasting, underground and surface mining, vamping and sweepings, support and tunnel rehabilitation, surface waste stripping and rehabilitation, and housekeeping and reclamation. Depending on the mine strategy, these can be core activities or non-core activities. In the case of the former, a mine provides an oversight supervision/management and mine planning and generally only take ownership of the mined product (e.g. ore) post mining (ex-pit or out of the mine). In the latter, a mine carries out main mining activities and outsources non-core activities or peripheral

activities to a mining contractor. Generally, this non-core activities are geared towards providing future flexibility, supplement mine output or maintain the general mine environment such that the appropriate level of mine health and safety is attained.

3.5.2. Original Equipment Manufacturers (OEM) of mining machines

The Technology Availability and Readiness Atlas (TARA) online database was launched by the Mandela Mining Precinct and Mining Equipment Manufacturers of South Africa (MEMSA) in November 2020 to allow local OEMs to showcase their commercially available products (Mining Equipment Manufacturers of South Africa, 2021). Some of the local OEMs of mining machines in the database are shown in Table 3-2.

Table 3-2: Some of the South African OEMs and types of mining machines listed in the TARA online database (Mining Equipment Manufacturers of South Africa, 2021).

OEM	Type of Machines		
HPE	• Hydropower drilling machines (self-propelled machine and hand-held machines) • Rock loaders		
Cheetah Technologies	• Chainsaw		
Novatek	• Hand-held drilling machines		
Aard	• Load haul and dampers (LHD) • Underground (UG) graders • UG articulated dump trucks (ADT) • UG Lubbe vehicles	• UG utility vehicles • UG Scaling & secondary rock breaking rigs • Drifters	• Drill rigs • Personnel transporters • Roofbolters
Rham Equipment	• LHD • UG utility vehicles • UG ADTs	• Roofbolters • Conveyor drives • UG Coal haulers	• UG Scissor lifts • UG mobile crane • UG Lubbe vehicles
Desmond Equipment	• Graders • Wheeled loaders • Drill rigs	• ADTs	
Fermel	• LHDs • UG graders • UG rigid frame haulers • UG charging vehicles • UG Concrete mixers • UG water canons	• ADTs • UG utility vehicles • UG mobile crane • UG Scissor lifts • UG wetcrete vehicles • UG extractors	• Personnel transporters • UG compactors • UG Scaling & secondary rock breaking rigs • UG Lubbe vehicles • Chock haulers
Conax Machine Solutions	• UG drill rigs • Surface drill rigs • Roofbolters	• Horizontal exploration drill rigs • UG mobile compressors	
Bird Machines	• UG compactors • UG Scissor lifts • UG ADTs	• UG mobile cranes • UG Scaling & secondary rock breaking rigs	• UG utility vehicles • Coal haulers • UG Lubbe vehicles
JA Engineering	• Continuous miners • Feeder breakers	• Scoops • Shuttle cars	• Roofbolters

The nine South African OEMs in Table 3-2 collectively manufacture 63 different types and 139 models of mining machines. Based on the machine types in Table 3-2, there is an inclination to conclude that the focus of South African mining OEM is mainly on underground equipment. It is nonetheless acknowledged that there are OEMs such as Bell Equipment (not in the database) and Desmond Equipment whose expertise is in the manufacturing of surface mining equipment.

It should be noted that not all OEMs are solely focused on manufacturing mining equipment. For example, Bell Equipment also manufactures equipment for the foresting industry and Galison (not in the database), in addition to mining equipment, manufactures transportation equipment for freight industry (grain, liquids and slag), although these equipment are not self-propelled.

In addition to local OEMs, there are international companies that import and sell mining equipment in South Africa, as well as providing support such as training, service, repairs and rebuild of equipment. Examples of such companies are Sandvik, Epiroc, Barloworld Equipment (Caterpillar) and Komatsu (inclusive of brands such as Joy Mining and Liebherr). There are also smaller players who are manufacturing companies in some respect and also importers such as Trident SA (underground hard rock mining equipment) and ELB Group (largely surface mining ground handling equipment).

3.5.3. Mining consulting companies

Consulting companies in South Africa provide a range of services that covers the entire mining value chain from exploration to commodity trading. In the mining engineering space, consulting companies provide a range of services that covers areas such as

mine planning, scheduling and design, resource and reserve evaluation, geotechnical services, financial valuation, mining systems optimisation, due diligence, project management, ventilation and refrigeration designs and optimisation, fleet selection and optimisation and management consulting.

Consulting companies largely rely on the expertise and experience of their employees or partners (consultants) for provision of services. This can be in the form of (1) experience and knowledge in the mining industry in general, in the mining of a specific commodity or commodities, in the mining of specific types of orebodies, or in the application of specific computer programmes; (2) subject matter experts, for example, geotechnical engineering, ventilation, survey, engineering geology, mine planning and design, and production scheduling; and (3) trouble shooting, for example, system optimisation, modelling and simulation, and equipment selection.

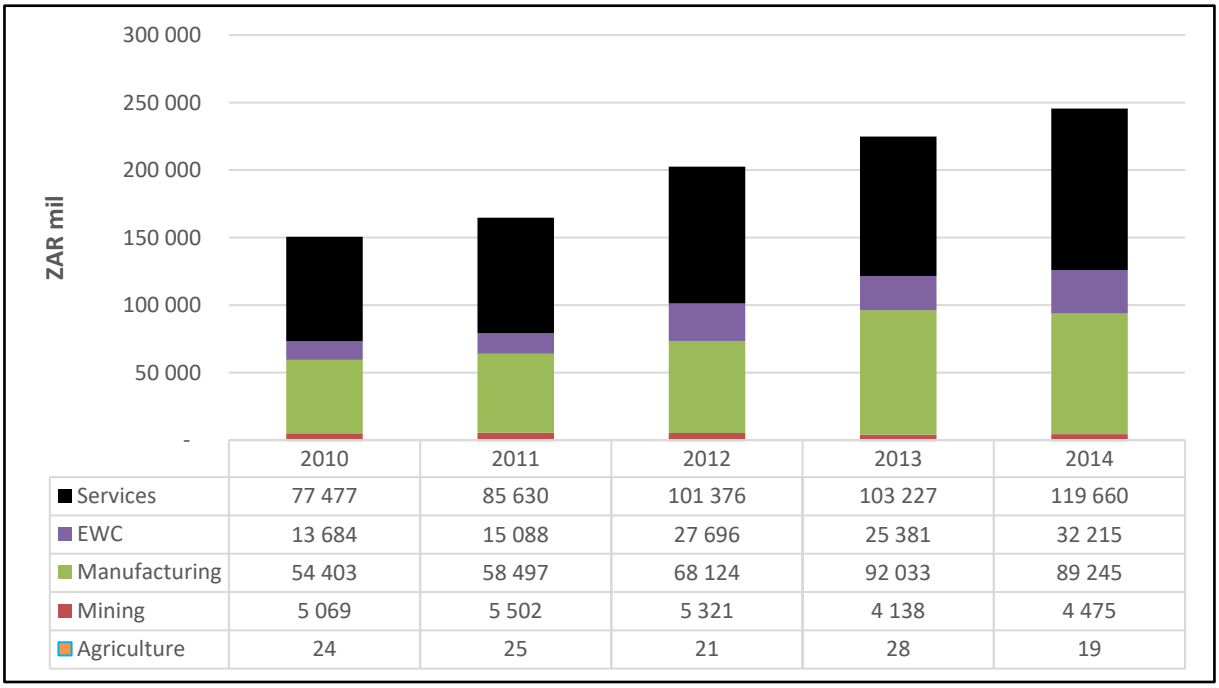
There are number of consulting companies that operate within South Africa and they include A&B Global Mining, Bara Consulting, BBE Consulting, Hexagon Mining Division, Jim Porter Mining Consulting, Mindset Mining Consultants, Minxcon, The MSA Group, Royal HaskoningDHV, RSV Group, Sound Mining Solution, SRK Consulting, Turgis Consulting, Ukwazi and VBKom. It should be noted that sometimes there is vertical integration in companies, for example Ukwazi is a consulting company that also undertakes contract mining and Murray & Roberts Cementation is a contract mining company that sometimes undertake consulting.

While the discussion in this section is limited to only three company types, it can be observed in Table 3-1 that there are different sectors that form part of the mining

backward linkage. Nonetheless, different company types relevant to this thesis are explained in Section 6.6.

3.6. Mining inputs and outputs in South Africa

The effects of mining backward (inputs) and forward linkages (outputs) can be understood better through the analysis of input-output tables. A close look at the South African input-output tables (supply-use tables) from 2010 to 2014 produced by Statistics South Africa (2017b) shows that mining in South Africa derived most of its inputs (excluding labour and taxes) from services and manufacturing sectors and less from energy, water and construction (EWC), mining industry and agriculture sector (see Figure 3-9). That is, when looking at Figure 3-9, mines in South Africa in 2010 bought mining products from other mines to the value of R5.07 billion and purchased products and services from domestic manufacturing companies and service providers amounting to R54.4 billion and R77.4 billion respectively. The purchase of products and services from domestic manufacturing companies and service providers increased to R89.2 billion and R119.7 billion in 2014.



	2010	2011	2012	2013	2014
Services	77 477	85 630	101 376	103 227	119 660
EWC	13 684	15 088	27 696	25 381	32 215
Manufacturing	54 403	58 497	68 124	92 033	89 245
Mining	5 069	5 502	5 321	4 138	4 475
Agriculture	24	25	21	28	19

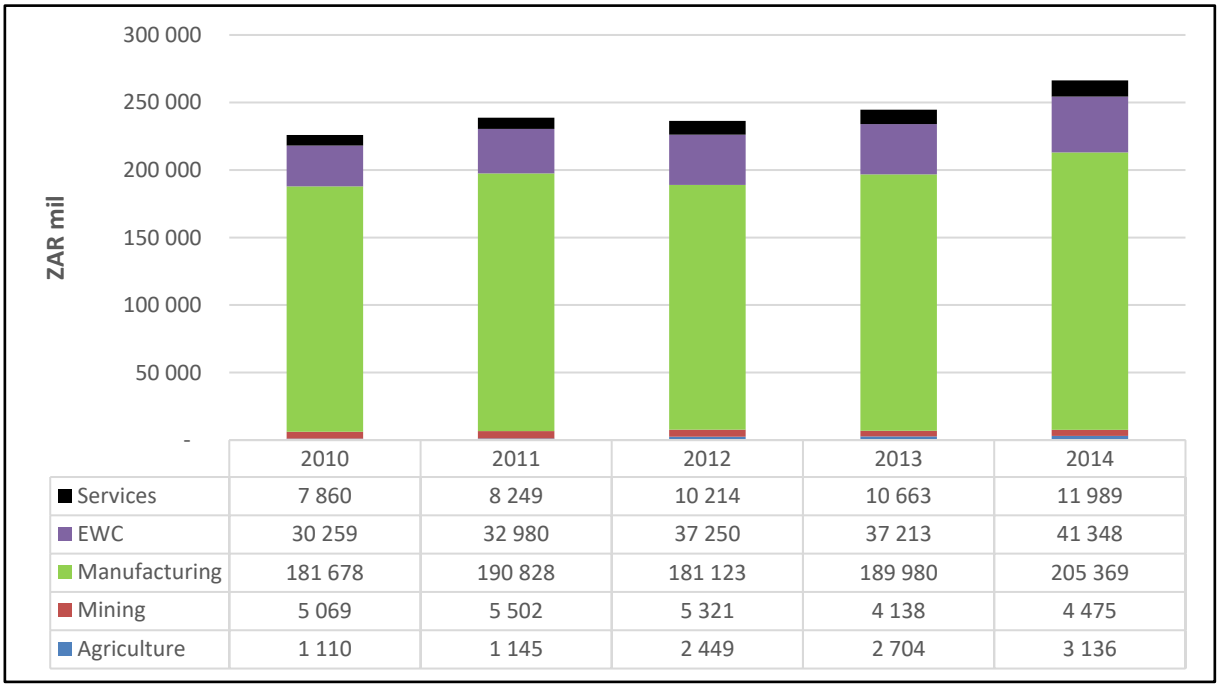
Figure 3-9: A trend in South African domestic mining backward linkages from 2010 to 2014 in current terms.

While Figure 3-9 and Figure 3-10 are not a true reflection of the value earned by domestic firms because the local content[22] is not taken into account, they are nonetheless still indicative of the strength of economic relationship between the local mining industry and other domestic sectors of the economy.

Maia (2014, p. 6) unpacked the South African mining industry's domestic backward linkages to show that goods and services flowing into mining are largely "machinery and equipment; transport equipment; wood products; fabricated metal products; non-metallic minerals (cement, bricks, etc.); chemicals and petroleum products; electricity; water; transport services; construction and civil engineering; finance and business services".

[22] The determination of local content value is beyond the scope of this research.

When considering mining forward linkages (beneficiation) and ignore the effects of exports and final consumption, i.e. considering only mining intermediary goods or the value of mining products sold to other domestic economic sectors, a different picture emerges (see Figure 3-10). Mining in South Africa is linked better with the manufacturing sector compared to other sectors. For example, in 2010 in Figure 3-10, mines sold the bulk of its products in monetary terms to the manufacturing sector (valued at R181.6 billion) compared to the other sectors (collectively the value was R44.3 billion). In 2014, the value of mining sales to the manufacturing sector increased to R205.4 billion while that of other sectors the combined value increased to R60.9 billion.



	2010	2011	2012	2013	2014
Services	7 860	8 249	10 214	10 663	11 989
EWC	30 259	32 980	37 250	37 213	41 348
Manufacturing	181 678	190 828	181 123	189 980	205 369
Mining	5 069	5 502	5 321	4 138	4 475
Agriculture	1 110	1 145	2 449	2 704	3 136

Figure 3-10: A trend in South African domestic mining forward linkages from 2010 to 2014 in current terms.

Maia (2014, p. 6) noted that the domestic mining industry has better downstream linkages with the following manufacturing industries: “basic metals (mainly the basic

iron and steel sector, which consumes iron ore); motor vehicles, parts and accessories (e.g. PGMs for catalytic converters); chemicals (e.g. phosphates for the fertiliser industry); petroleum refineries (e.g. coal for Sasol's operations); electricity (e.g. coal for Eskom's power generation); construction and civil engineering (e.g. building materials); and other industries such as jewellery manufacturing (e.g. gold, platinum)".

As demonstrated in Figure 3-1 and Figure 3-2 that South Africa is largely a service economy, the same takes a lion's share of the domestic mining procurement value as shown in Figure 3-9. As expected, mines are almost exclusively product-based enterprises; therefore, the value of their goods overshadows the value of its services as shown in Figure 3-10.

However, the linkages of the South African mining industry and the manufacturing sector cannot be understated. Both the backward and forward linkages of mining with the manufacturing sector are significant. Many industries highlighted by Maia as having both significant forward and backward linkages with mining fall under the manufacturing industry and services sectors. It can, therefore, be concluded that the South African mining industry has strong backward and forward linkages with the domestic manufacturing and services sectors.

3.7. Summary

The purpose of this chapter was to provide an overview of linkages, in particular backward linkages between the South African mining industry and the rest of the economy. These linkages exist within the understanding that South Africa is a constitutional democracy with an estimated population of 55.6 million people in 2016, with 54% of whom found in three of the nine provinces namely Kwa-Zulu Natal,

Gauteng and Western Cape. These provinces contributed 60% to the GDP of the country in 2016.

Linkages are driven by human resource and there have been notable strides made on the education front. The illiteracy level has dropped from 9.3% in 1996 to 4.1% in 2016, while the portion of the population with tertiary qualification increased from 1% to 2.2% over the same period.

Like many countries in the world, the economy of South Africa was agrarian before the advent of large industrial scale mining in the 1870s after the discovery of diamonds in Kimberley. The discovery of gold deposits in the Witwatersrand Basin in the 1880s firmly established South Africa as a mining destination. Coalfields near Vereeniging and Bethal that were discovered earlier were instrumental in supplying the mines with coal for energy.

As the number and size of mines grew, so did the demand for mining inputs. This growth in demand led to the establishment of transportation services (e.g. transportation of coal) and manufactured products. For example, due to the hardness of the quartzite rock in the Witwatersrand Basin, drilling and blasting were necessary. The response was the establishment of factories that manufactured hand-held rock drilling equipment and explosives in South Africa. The consumption rate of explosives at some point made South Africa the largest manufacturer of dynamite in the world, while further developments of the hand-held rock drills by COMRO led to the discovery of hydropower technology for deep and hot mines. With this technology, new types of underground rigs emerged in the 1990s.

Mining and its associated demands over time contributed to the transformation of South African economy from agrarian to industry based. Industry in this case is the super sector that includes mining, manufacturing, construction, and energy among others. As the economy became sophisticated, the demand for services also grew. It is estimated that in the late 1980s the contribution of services to the GDP was roughly the same as that of industry, but the growth of the former accelerated in the 1990s resulting in a service dominated economy as shown in Figure 3-2.

An analysis of the South African input-output tables from 2010 to 2014 shows that the country's mining industry has strong forward linkages with the domestic manufacturing industry if the effects of exports are ignored. With respect to backward linkages, it can be observed in Figure 3-9 that mining's largest inputs, in terms of value when the effects of local content inputs are ignored, is the services sector. This is also collaborated in Table 3-1. Services in this case encompass activities such as contract mining, consulting, and equipment service, repair and rebuild. The second largest set of inputs are manufactured goods. It is, therefore, safe to conclude that the South African mining industry has strong forward and backward linkages with the domestic manufacturing sector and with even stronger backward linkages with the services sector.

Central to the provision of goods and services within linkages are human resources. Chapter 4, in this context, explores types of occupation that are relevant for provision of goods and services in the South African mining production backward linkage envelope.

4. Occupations in the mining production backward linkage envelope in South Africa

4.1. Introduction

In Chapter 3 it was noted that the South African mining industry has strong backward and forward linkages with the local manufacturing sector. It was demonstrated that the industry has stronger backward linkages with the services sectors compared to the manufacturing sector. In addition, the annual growth in the procurement value of input products and services suggests that the industry's appetite for local inputs is growing.

Manufacturing, which supplies the required input products, is comprised of specialised activities requiring a certain level of training of workers involved. Similarly, services are expected to be executed by persons with adequate understanding of the services they provide to their clients. It can therefore be said that there is an expectation that behind mining inputs (goods and services) there will be a workforce (men and women) with a certain level of qualifications and competency.

It is with this notion that this chapter explores the evolution of organisational structures with an attempt to draw its linkage with the classification of occupations and further explore the implication of fourth industrial revolution (4IR) on jobs in the mining production backward linkage envelope in South Africa. The notion of organisational structure has precipitated the division of labour and the efficiency required from labour as well as the complexity of tasks involved. In turn the need for

universal classification of occupations arose as companies expanded their operations into different countries for ease of comparison and grading.

The task of classifying occupations needs a firm understanding of skills level and specialisation in each activity that forms an occupation. These two result in the classification of occupations which have strong links with organisational hierarchy. Skill level and specialisation are dynamic in that they evolve due to the dictates of technology employed. The three previous industrial revolutions and the current 4IR have resulted in both the redundancy and creation of some of the old and new occupations, respectively.

4.2. Brief overview of organisational structure

It is believed that the organisational structure of companies was borrowed from military formations during the first industrial revolution in the 18th and 19th century (Talbot, 2003). Prior to the industrial era, the biggest organised structures known in the Western world were churches, state and military (McMillan, 2002). The Roman Empire legion, under Emperor Marcus Aurelius from 121 to 180 AD, consisted of between 350 000 and 400 000 soldiers employed to conquer nations and defend the empire, as well as controlling and enforcing the Roman rule in a geographically dispersed empire (Dupuy and Dupuy, 1993). This feat was achieved, among others, through a structure depicted in Figure 4-1.

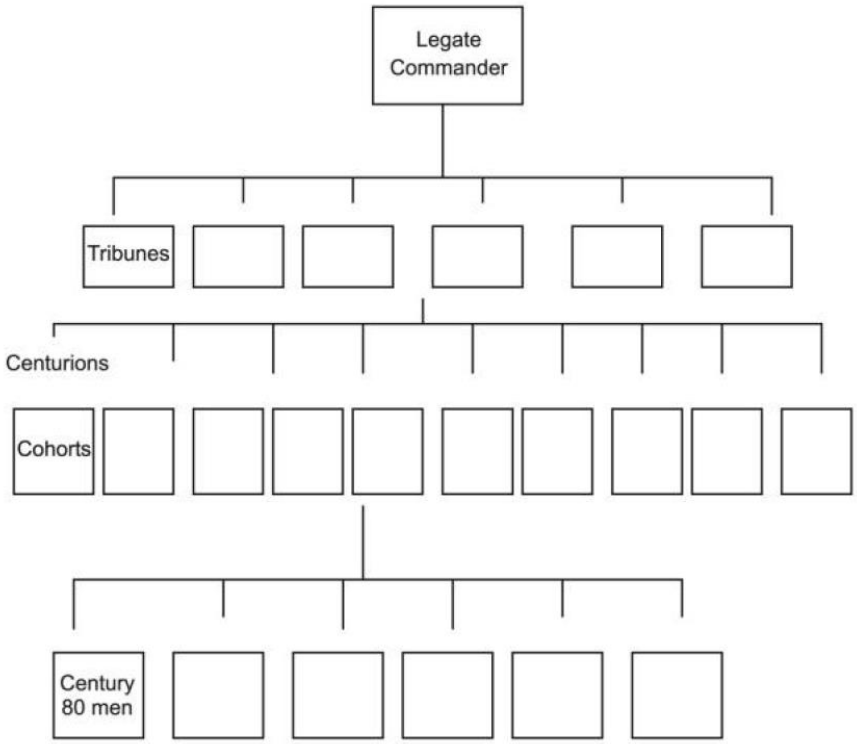


Figure 4-1: A typical structure of the Roman legion (Talbot, 2003).

Before the industrial era, productive activities were carried out either through small businesses or by self-employed individuals with unitary structures. At the dawn of the first industrial revolution, it became necessary to form bigger organisations aimed at carrying out productive activities at an industrial scale. This gave rise to the need to capitalise organisations, organise work along functions, and supervise workers (labour) whose numbers were growing as more people opted for employment in big organisations rather than being self-employed (many historical graft vocations were threatened by mechanisation in big factories at this stage). The complexity of these new organisations gave rise, as a necessity rather than luxury, to organisational hierarchy where at the apex were capitalists or their proxies who relied on an intermediate layer of managers to organise and control labour (McMillan, 2002 and Talbot, 2003).

This gave rise to the profession of business administration which was undertaken by salaried managers in organisations as proxies of the traditionally aloof business owners who would customarily leave the direction and growth of their businesses largely at the mercy of market forces. Chandler (1977) called the phenomenon of actively managed companies by salaried managers a visible hand, which is the opposite of the market force led growth or an invisible hand as advocated by Adam Smith. According to Chandler (1977), organisations that were managed by salaried professional managers in USA emerged after WWI.

Under the visible hand phenomenon, business owners hired salaried senior managers, who in turn hired middle managers, who in turn hired supervisors to look after the labour that carried out productive tasks in organisations. Supervision and tasks were further divided into functions or silos, resulting in a vertical and horizontal organisational matrix, and differences in salaries; with senior managers earning more than lower ranked labourers. This new way of organising enterprises gave rise to multi-unit organisations as opposed to the previously single unit organisations. The multi-unit structure, known as the M-structure, is shown in Figure 4-2 and bears similarities with military structures shown in Figure 4.1. The M-structure enabled managers at different levels to plan, direct, organise and coordinate organisational activities (Chandler, 1977 and McMillan, 2002).

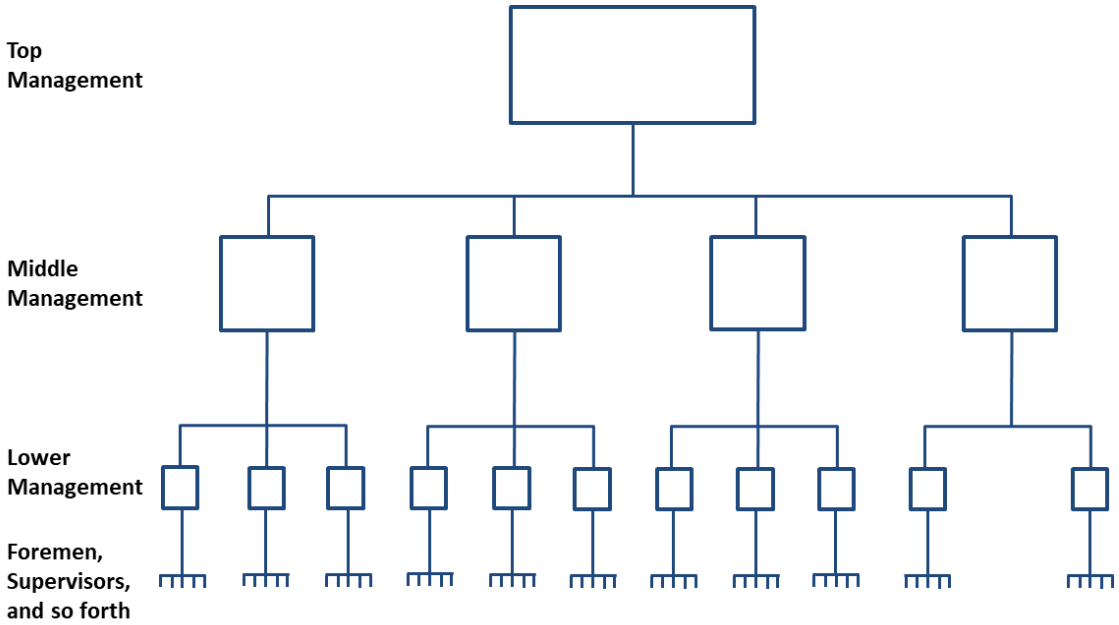


Figure 4-2: The M-structure adopted by businesses during the industrial era (Chandler, 1977).

4.3. Division of labour in organisations

The industrial revolution with its inherent M-structure in organisations invariably resulted in the division of labour with built-in differences in roles and responsibilities. This is deemed necessary as it enables organisations to efficiently satisfy market demands. In organisations (particularly in manufacturing firms), the division of labour constitutes a subdivision of productive tasks during the production process. This subdivision can also be extended to services if such services require skills of different trade persons such as diesel-mechanics, auto-electricians, and software specialists in the case of load and haul fleet service and maintenance for example.

The division of labour was advocated due to improvement in productivity (more units produced per labour or less service time), low cost of production (more output per

labour due to task specialisation), higher profits in cases where prices are rising and production cost is stable or increasing at a lower rate than that of prices; or where prices are stable and production cost is falling. In manufacturing, division of labour resulted in production of more units (widgets) per labour for more profits (Rodriguez-Clare, 1996; Negishi, 2000; and Scicluna, 2015).

The disadvantages of division of labour at the factory level, as stated by Karl Marx in Llorente (2006) and Scicluna (2015), were the subjection of labour to the control of capital; the subdivision of productive activities which results in monotonous tasks and in turn diminishes labour's cognitive ability in the long run; and the low remuneration that creates disempowered proletariat class. Dilchert et al. (2007) demonstrated that low cognitive ability among workers correlates with counterproductive work behaviour (e.g. theft, absenteeism or violence) and consequently loss in revenue. The underlying causes (even though the study by Dilchert et al. (2007) was not conclusive) could be low education level and loss of ambition associated with low income. As it will be demonstrated later, these monotonous tasks (particularly repetitive tasks) associated with low cognitive ability are at the risk of being obsolete in the 4IR work environment.

4.4. Classification of occupations

Due to the introduction of business administration (managerial layer in organisations) during the first and second industrial revolutions, division of labour in organisations, and complex societal needs (demand for different products and services), different occupations were developed as prime drivers of economic gains as opposed to craft

(trade work) before the industrial revolutions. Some of these occupations in different countries were called by different names, but doing the same thing and others were called by the same name, but doing completely different things. As the cost of transportation became affordable, resulting in easier labour mobility and due to globalisation, there was a need to come up with a global classification of occupations for ease of comparison (Hoffmann, 1999).

4.4.1. Occupation classification systems

To understand the classification system of occupations, it is important to consider some basic definitions. Statistics South Africa (2012, p. 2) defined a job as a "set of tasks and duties performed, or meant to be performed, by one person, including an employer or person in self-employment"; and occupation as a "set of jobs whose main tasks and duties are characterised by a high degree of similarity". Furthermore, Hoffmann (1999, p. 4) defined classification of occupations as "a tool for organising all jobs in an establishment, an industry or a country into a clearly defined set of groups according to the tasks and duties undertaken in the job".

The basic list of international classification of occupations can be found in a document called International Standard Classification of Occupations (ISCO), prepared by the International Labour Organisation (ILO), a unit under the United Nations. The ISCO has numerous objectives, chief among them is to enable the comparison of occupations across different nations and to perform statistical analysis of the labour market for policy formulation (Hoffmann, 1999).

The international classification of occupations was first discussed in 1923, but the first publication was in 1958 and was called ISCO-58. All ISCO publications are partitioned into two elements, namely the descriptive component and classification system. The descriptive component is “a set of titles of occupations and occupational groups, but which usually consists of descriptions of the tasks and duties as well as other aspects of the jobs which belong to each of the defined groups” (Hoffmann, 1999, p. 4) and the classification system “gives the guidelines on how jobs are to be classified into the most detailed groups of the classification and how these detailed groups are to be further aggregated into broader groups” (*ibid.*).

Table 4.1 shows the classification of occupations where three different classification systems acknowledged in South Africa are compared. It can be noticed in Table 4-1 that ISCO-08 and SASCO 2011 have nine major groups of occupations compared to the 2013 version of South African’s occupation classification framework or Organising Framework for Occupations (OFO) which has eight major groups. The difference between SASCO 2011 and OFO 2013 stems from the difference in approach as discussed below.

Table 4-1: Comparison of classification of occupations between ISCO-08, SASCO 2011 and OFO 2013 (Statistics South Africa, 2012 and Department of Higher Education and Training, 2013).

Groups of classification	ISCO-08	SASCO 2011	OFO 2013
Major Groups	9	9	8
Sub-major Groups	43	41	39
Minor Groups	130	131	125
Unit Groups	436	440	440

For the purpose of statistical reporting in South Africa, Statistics South Africa uses the South African Standard Classification of Occupations (SASCO) which is aligned to ISCO-88 and ISCO-08. The data used in the compilation of SASCO come from reports such as population census, causes of death, marriages and divorces statistics, and the Quarterly Labour Force Survey (Statistics South Africa, 2012a).

However, as early as 2004 the Department of Labour (DoL) was of the view that SASCO was inadequate for labour planning purposes. As a consequence, DoL aligned its labour planning framework with the Australian and New Zealand Standard Classification of Occupations (ANZSCO) which reflected the work environment more accurately than SASCO. The ANZSCO in Australia and New Zealand was used in a process of classifying and coding occupations under OFO, which is a bottom up approach of categorising similar jobs into occupations and classifying these occupations into occupational groups. This was deemed to be a better framework than the one used in SASCO. The DoL formerly adopted OFO process in 2005 (Department of Higher Education and Training, 2013).

In 2009, the responsibility of classifying occupations using the OFO process in South Africa was taken over by Department of Higher Education and Training (DHET). In 2010, DHET sought to harmonise its version of OFO with SASCO by aligning with ISCO-08 which then had taken into consideration international developments in information and communication technology sector. In the OFO-2012 and OFO-2013 versions, the green technology occupations were incorporated into the classification framework (Department of Higher Education and Training, 2013). The OFO process

has continued to change in South Africa and the latest version used in this thesis hence forth is OFO-2017.

4.4.2. Skills

To successfully carry out a job within an occupation, one needs a skill. There are two dimensions to a skill, namely skill level and skill specialisation. Both these dimensions are taken into account when classifying occupations into groups.

4.4.2.1. Skills level

According to the Department of Higher Education and Training (2013; p. 6), a “skill level is defined as a function of the complexity and range of tasks and duties to be performed in an occupation”. It also takes into account the level of education and on-the-job training and/or experience required for competent performance.

According to the Department of Higher Education and Training (2018), there are four prescribed OFO skill levels. The first skill level is equivalent to a basic primary school education; the second skill level is equivalent to a secondary school education; the third level is equivalent to school leaving qualification; and the fourth level skills are qualifications post school leaving qualification. Table 4-2 shows the mapping of OFO skill levels to education levels (bands) and the National Qualification Framework (NQF) levels in South Africa.

Table 4-2: The mapping of education and qualification levels to OFO skill levels in South Africa (The South African Qualifications Authority, 2012; The South African Qualifications Authority, 2015; and Department of Higher Education and Training, 2018).

Levels of education in South Africa				OFO 2017
Education Band	**School Grade**	**NQF level**	**Qualifications**	**Skill levels**
Higher		10	Doctoral degree;	4
		9	Masters' degree	
		8	Honours degree; Postgraduate diploma	
		7	Bachelor's degree; Advanced diploma	
		6	Diploma; Advanced certificate	
		5	Higher certificate	
Intermediate	12 (School leaving)	4	National certificate	3
	11	3	Intermediate certificate	2
	10	2	Elementary certificate	
General	9	1	General certificate	
	8			1
	7			
	6			
	5			
	4			
	3			
	2			
	1			
	R			

Table 4-3 shows the mapping of skill levels to OFO 2017's major groups of occupations. It can be deduced from this table that there is a strong link between how major groups of occupations were composed and the organisational hierarchy (M-structure). As one moves from elementary positions (Major Group 8 in Table 4-3) to managers (Major Group 1), there is a general expectation that the number of

employed people will be reduced in most industries. This also applies to the numbers of qualifications per NQF level within an organisation, where there is a general expectation that senior managers will have higher qualifications and/or more experience than those in junior positions. These general expectations are in line with the educational level of employees in Australia and Ghana discussed in Chapter 2, for example.

Table 4-3: The mapping of skill levels to OFO 2017 major groups of occupations (Department of Higher Education and Training, 2018).

Major Groups of Occupations	Skill Level
1. Legislators, senior officials, managers and company directors	3 & 4
2. Professionals	4
3. Technicians and associate professionals	3
4. Clerks	2
5. Service workers and shop and market sales workers	2
6. Skilled agricultural and fishery workers	2
7. Plant and machine operators and assemblers	2
8. Elementary occupations	1

4.4.2.2. Skills specialisation

A skill specialisation takes into account “the field of knowledge required; the tools and machinery used; the materials worked on or with; and the kinds of goods and services produced” (Department of Higher Education and Training, 2013: p. 7). This talks to an in-depth knowledge (compared to general knowledge) required in the execution of tasks defining an occupation. This can be cognitive ability, subject knowledge, or knowledge of usage of specialised machines or tools. The combination of skills level and skill specialisation generally is an indication of the competency level of an

individual in an occupation. Skill specialisation can become a barrier if employees are to be reskilled during redundancy as it is a function of opportunity, dexterity and aptitude.

4.5. Occupations in the mining production backward linkage envelope

It is largely expected that individuals performing tasks with respect to production and provision of goods and services within the mining production backward linkage envelope will have the requisite skill level and specialisation. In South Africa, institutions charged with the responsibility of providing the required education and training, particularly at the first, second and third OFO skill levels, are Sector Training and Education Authorities (SETA).

SETAs were established in March 2000 under the auspices of the DoL. There were originally 23 SETAs established in terms of the Skills Development Act, No. 97 of 1998 to replace the 33 industry training boards whose main focus was to train apprentices. In the views of the new regime installed in 1994 in South Africa, the focus on apprenticeship was limited and wanted the scope to be extended to include (in addition to apprenticeship) learnerships, internships and unit based skills programmes such that all the sectors of the economy are covered and workers benefit equally (Anon, n.d.). This new and broader focus was informed by the National Skills Development Strategy (NSDS) which was a response of the South African government's desire to improve the country's global competitiveness through human resource skills.

The NSDS was necessary because before 1994, training was polarised along racial lines and gender to the benefit of mainly European males, underpinned by the exclusionary policies of the Apartheid system. The main thrust of the NSDS was to transform the racial and gender inequalities in the workplace through acquisition of skills (particularly among those who were previously marginalised); align individual skill development needs with the skill requirements of the economy; and increase training capacity, quality and access for the benefit of all workers (Anon, n.d.).

The NSDS, under the DoL, was underpinned by three legislations, namely the Skills Development Act, No. 97 of 1998; the Skills Development Levies Act, No 9 of 1999; and the Employment Equity Act, No. 55 of 1998. The two critical and principal implementers of the NSDS were SETAs and the National Skills Fund (NSF) (Department of Labour, 2010). The latter is a public entity established in 1999 in terms of Section 27 of the Skills Development Act to primarily provide funds towards skills development of workers. The NSF principally receives funds from the 20% of skills levies paid by companies to a SETA assigned to their industry, fiscal allocation, interest earned from investments in the Public Investment Company (PIC), donors, and other sources (Department of Labour, 2019).

SETAs use service providers such as universities, Technical and Vocational Education and Training (TVET) colleges and private companies for the education and training of workers. In 2010, the political oversight and control of SETAs moved from the DoL to the Department of Higher Education and Training (DHET) which oversees education and training in TVET colleges and universities in South Africa. In the same year, the landscape of SETAs was realigned and as a consequence, were reduced

from 23 to 21 (Anon, n.d.). Table 4-4 lists the current 21 SETAs charged with the responsibility of providing opportunities for skills development among South African workers (including prospective workers).

Of the 21 SETAs listed in Table 4-4, only five namely merSETA, MQA, MICT SETA, SSETA, and ETDP SETA can be said to have developed qualification programmes that are directly linked to occupations in the mining production backward linkage envelope in South Africa, in so far as mining input technology is concerned. The lists of these qualification programmes are shown in Table 4-5. It should be noted that the SETAs in Table 4-5 offer more qualification programmes which are relevant to other industries than those listed therein.

Table 4-4: A list of 21 SETAs in South Africa (Department of Higher Education and Training, 2019).

Full Name	Short Name
Agricultural Sector Education and Training Authority	AgriSETA
Banking Sector Education and Training Authority	BANKSETA
Chemical Industries Education and Training Authority	CHIETA
Construction Education and Training Authority	CETA
Culture, Arts, Tourism, Hospitality and Sport Sector Education and Training Authority	CATHSSETA
Education, Training and Development Practices Sector Education and Training Authority	ETDP SETA
Energy and Water Sector Education and Training Authority	EWSETA
Fibre Processing and Manufacturing Sector Education and Training Authority	FP&M SETA
Finance and Accounting Services Sector Education and Training Authority	FASSET
Food and Beverage Manufacturing Industry Sector Education and Training Authority	FoodBev SETA
Health and Welfare Sector Education and Training Authority	HWSETA
Insurance Sector Education and Training Authority	INSETA
Local Government Sector Education and Training Authority	LGSETA
Manufacturing, Engineering and Related Services Sector Education and Training Authority	merSETA
Media, Information and Communication Technologies Sector Education and Training Authority	MICT SETA
Mining Qualifications Authority	MQA
Public Service Sector Education and Training Authority	PSETA

Safety and Security Sector Education and Training Authority	SASSETA
Services Sector Education and Training Authority	SSETA
Transport Education Training Authority	TETA
Wholesale and Retail Sector Education and Training Authority	W&RSETA

Table 4-5: List of qualifications offered by SETAs in South Africa for backward industries in mining (Hall, 2016a, Hall, 2016b, Hall, 2016c, Mokiti, 2017, and MICT SETA, 2018).

SETA Qualification Titles				
merSETA	**MQA**	**MICT SETA**	**SSETA**	**ETDP SETA**
Autotronics (NQF level 4, 5)	Automotive Repair and Maintenance (NQF level 2, 3, 4)	Information Technology: Technical Support (NQF level 4)	Customer Management (Level 5)	Occupationally Directed Education Training and Development Practices (Level 4, 5)
Business Consulting Practice (Enterprise Resource Planning) (NQF level 5)	Continuous Miner Operations Underground Coal (NQF level 3)	GUI-Based Applications for End-User Computing (NQF level 3)	Team Leader (NQF level 4)	
Carbonate Materials Manufacturing Processes (NQF level 4)	Diesel Mechanic (NQF level 3, 4)	Information Technology: Systems Development (NQF level 4)	General Management (NQF level 5)	
CNC Production Machining (NQF level 4, 5)	Electrical (NQF level 4)	Masters in Information Engineering (NQF level 7)	Generic Multi Sector Project Management (NQF level 4)	
Electrical Engineering (NQF level 2, 3, 4)	Electro-Mechanics (NQF level 2, 3, 4)	Masters in Telecommunications Engineering (NQF level 7)	Project Management (NQF level 5)	
Electrics: Chemical Electrical (NQF level 4)	Engineering Maintenance for Underground (coal, hard rock & surface mining) (NQF level 2)	Solutions Development / Programming (NQF level 5)	Marketing (NQF level 3, 4, 5, 7)	
Electrics: Chemical Instrumentation (NQF level 4)	Fitting (Including Machining) (NQF level 2)	Systems Development (NQF level 4,5)		
Electro-Mechanical Winding (NQF level 4)	Fitting and Turning (NQF level 3)	Systems Support (Desktop) (NQF level 5)		
Electro-Mechanics: Manufacturing Engineering (NQF level 4)	Instrumentation Mechanician (NQF level 3)	Systems Support Engineer (NQF level 5)		
Electronics: (Electronics Manufacturing) (NQF level 4)	Lamproom Operations (NQF level 3)			
Engineering Fabrication: Manufacturing & Engineering (NQF level 4)	Measurement Control and Instrumentation (NQF level 2, 3, 4)			
Fluid Power (NQF level 4, 5)	Millwright (NQF level 4)			
Generic Management: Generic Manufacturing (NQF level 5)	Mineral Sampling (NQF level 2)			
Generic Management: Inventory and Inventory Control (NQF level 4)	Mineral Surveying (NQF level 2, 3, 4)			

Generic Management: Manufacturing Control (NQF level 4)	Mining Operations – Surface (Non-Blasted Route) (NQF level 4)			
Generic Management: Planning And Scheduling Techniques (NQF level 4)	Mining Operations – Surface (Blasted Route) (NQF level 4)			
Generic Management: Process Manufacturing (NQF level 4)	Mining Operations (coal, hard rock & surface mining) (NQF level 1, 2, 3, 4)			
Industrial Rubber Manufacturing (NQF level 4, 5)	Mining Technical Support (Geology) (NQF level 2)			
Information Technology: Technical Support (NQF level 4)	Occupational Health, Safety and Environment (NQF level 2)			
Inspection And Assessment (Non-Metallics) (NQF level 4, 5)	Occupational Hygiene and Safety (NQF level 3)			
Lifting Machinery Inspection (NQF level 5)	Plater/Welder (NQF level 3)			
Maintenance Coordination (NQF level 5)	Rigging Ropesman (Generalist) (NQF level 3)			
Manufacturing and Assembly Logistics (NQF level 4)	Rock Engineering Strata Control Operations (coal, hard rock & surface mining) (NQF level 2)			
Manufacturing and Assembly Operations Supervision (NQF level 4)	Rockbreaking Underground (NQF level 3)			
Manufacturing Management (NQF level 5)	Strata Control Operations (NQF level 4)			
Mechanical Engineering: Fitting and Machining (NQF level 4)	Surface Excavations (Blasted Route) (NQF level 4)			
Mechanical Engineering: Fitting (NQF level 2, 3, 4)	Surface Mining Rock Breaking (NQF level 2)			
Mechanical Engineering: Machining And Tooling (NQF level 4)	Underground Hard Rock Narrow Tabular (NQF level 2, 3)			
Mechanical Engineering: Pipe-Fitting (NQF level 4)				
Mechanical Handling: Rigging (NQF level 2, 3, 4)				
Mechanics: Chemical Fitting (NQF level 4)				
Mechatronics (NQF level 2, 3, 4)				
Metal & Engineering Manufacturing Processes (NQF level 2, 3, 4)				
Optical Manufacturing Processes (NQF level 4)				
Plastics Manufacturing (NQF level 2, 3, 5)				
Polymer Composite Fabrication (NQF level 2, 3, 4)				
Rubber Technology (NQF level 5)				

Table 4-5 also indicates the NQF level at which the listed programmes are offered, and this in turn can be linked to the skill levels and qualifications in Tables 4-2 and major groups of occupations in Table 4-3. From Table 4-5, it can be noticed that the merSETA and MQA offer more programmes relevant to companies in the mining production backward linkage envelope, mostly at NQF levels 2, 3 and 4 (equivalent to OFO skill level 2). On the other side, MICT SETA, SSETA, and ETDP SETA tend to offer relevant programmes at NQF level 5 and higher (equivalent to OFO skill level 3 and 4). The training programmes relevant to elementary occupations (OFO skill level 1) appear to be left largely to the companies with such positions.

4.6. Potential effects of 4IR on backward linkage occupations

The world has gone through three industrial revolutions and currently we are in the fourth industrial revolution or 4IR. The first industrial revolution took place between 1760 and 1900 and was characterised by the invention of steam engines that powered textile and steelwork industries with mechanisation being a good general description of this revolution. The second industrial revolution took place between 1900 and 1960 and was characterised by the invention of the internal combustion engines and assembly lines in factories. Mass production and globalisation are good general descriptions of the second industrial revolution. The third industrial revolution was experienced between 1960 and 2000 and was characterised by the invention of computers, robots, internet, cellular telephony and the emergence of ICT industry with digitisation and automation being the appropriate general description of

significant technology breakthrough of this era. The 4IR emerged in 2000 and is characterised by green energies, internet revolution, 3-D printing and genetic engineering with convergence of various technologies being the main feature of this revolution (Xu et al., 2018 and Cunningham and Nyakabawo, 2018). Every industry is interrupted by 4IR, with the mining industry's version of 4IR being named Mining 4.0.

Each of the three previous industrial revolutions created opportunities for the creation of new occupations, while at the same time caused redundancy of some of the old occupations. This trend is expected to continue in the current revolution (Xu et al., 2018). According to Centre for the New Economy and Society (2018), an average of 71% of the total task hours in industries the centre has surveyed in 2018 was performed by humans and only 29% was performed by machines. This split is expected to shift to 58% task hours performed by humans and 42% task hours performed by machines by 2022. This is a significant shift in four years, which will bring a major disruption in many occupations (World Economic Forum, 2018).

Frey and Osborne (2013) compiled a list of occupations (a total of 702 occupations) and ranked them from a low probability of being computerised to high probability of being computerised. From this list, 65 occupations that fall within the mining production backward linkage envelope in South Africa were extracted (see Table 4-6). From Table 4-6, occupations with a probability of 0.2 and higher of being computerised mainly fall under Major Groups 4 to 8 (see Table 4-3). These are occupations mainly within OFO skill levels 3, 2 and 1. Based on Table 4-2, the educational level required to perform tasks within these occupations is a school

leaving qualification (or equivalent) and less. The implication is that there is a high probability that 4IR will put job security of people with only or less than post school leaving qualification at risk.

Table 4-6: List of occupations in the mining production backward linkage envelope in South Africa with probability of being computerised (Frey and Osborne, 2013).

Probability of Computerisable	Mining Production Backward Linkage Occupations	Major Occupation Group
0.003	First-Line Supervisors of Mechanics, Installers, and Repairers	1
0.0041	Sales Engineers	2
0.0055	Human Resources Managers	1
0.0063	Training and Development Managers	1
0.0065	Computer Systems Analysts	2
0.0095	Teachers and Instructors, All Other	2
0.01	Education Administrators, Postsecondary	4
0.011	Mechanical Engineers	2
0.013	Sales Managers	1
0.014	Hydrologists	2
0.014	Training and Development Specialists	2
0.014	First-Line Supervisors of Office and Administrative Support Workers	1
0.015	Computer and Information Research Scientists	2
0.015	Chief Executives	1
0.016	First-Line Supervisors of Production and Operating Workers	1
0.017	Chemical Engineers	2
0.029	Industrial Engineers	2
0.029	First-Line Supervisors of Transportation and Material-Moving Machine and Vehicle Operators	1
0.03	Industrial Production Managers	1
0.03	Industrial Engineering Technicians	3
0.03	Network and Computer Systems Administrators	2
0.03	Database Administrators	2
0.03	Purchasing Managers	1
0.033	Environmental Scientists and Specialists, Including Health	2
0.035	Computer and Information Systems Managers	1
0.042	Software Developers, Applications	2
0.069	Financial Managers	1
0.1	Electrical Engineers	2
0.13	Software Developers, Systems Software	2
0.14	Mining and Geological Engineers, Including Mining Safety Engineers	2
0.17	First-Line Supervisors of Construction Trades and Extraction Workers	1
0.24	Engineering Technicians, Except Drafters, All Other	3
0.25	Occupational Health and Safety Technicians	3

Probability of Computerisable	Mining Production Backward Linkage Occupations	Major Occupation Group
0.25	Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products	3
0.38	Mechanical Engineering Technicians	3
0.4	Mobile Heavy Equipment Mechanics, Except Engines	6
0.41	Structural Metal Fabricators and Fitters	6
0.41	Electrical and Electronics Repairers, Commercial and Industrial Equipment	6
0.42	First-Line Supervisors of Helpers, Laborers, and Material Movers, Hand	1
0.48	Explosives Workers, Ordnance Handling Experts, and Blasters	6
0.49	Roof Bolters, Mining	7
0.5	Installation, Maintenance, and Repair Workers, All Other	6
0.54	Continuous Mining Machine Operators	7
0.55	Customer Service Representatives	4
0.57	Chemical Technicians	3
0.59	Millwrights	6
0.59	Mine Cutting and Channeling Machine Operators	7
0.61	Electronic Equipment Installers and Repairers, Motor Vehicles	6
0.64	Stock Clerks and Order Fillers	4
0.65	Machinists	6
0.65	Computer Support Specialists	2
0.82	Engine and Other Machine Assemblers	7
0.82	Sheet Metal Workers	8
0.83	Structural Iron and Steel Workers	8
0.84	Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic	7
0.85	Chemical Plant and System Operators	7
0.89	Riggers	6
0.9	Pump Operators, Except Wellhead Pumpers	8
0.91	Electrical and Electronics Installers and Repairers, Transportation Equipment	6
0.92	Production Workers, All Other	8
0.93	Service Unit Operators, Oil, Gas, and Mining	7
0.93	Industrial Truck and Tractor Operators	7
0.95	Operating Engineers and Other Construction Equipment Operators	7
0.97	Electromechanical Equipment Assemblers	7
0.97	Payroll and Timekeeping Clerks	4

Frey and Osborne (2013; p. 93) stated that “Low skilled and low wage jobs will be replaced by computers and digitization. The higher paid jobs requiring more skills are less likely to be replaced. This increased dichotomization can lead to an increase in social tensions”. The social tension will rise due to redundant labour and also due to

disproportional wealth creation propensity of industrial revolutions. For example in the third industrial revolution, three biggest companies in Detroit in 1990 with only 1.2 million employees had a market capitalisation of US$36 billion; and now in 4IR, the three biggest companies in Silicon Valley in 2014 with only about 120 000 employees had a market capitalisation of US$ 1.09 trillion (Gatune and de Boer, 2019). This is an indication (but not proof) of wealth concentration propensity of industrial revolutions. On the other hand, Xu et al. (2018) are of the view that disruption technologies in 4IR will benefit people by lowering the cost of doing business and by extension prices and furthermore it will be relatively easier to start new businesses.

It is, however, worth noting that 4IR will most likely create more jobs than those that will be redundant. The downside of this seemingly good news for a country such as South Africa is that new jobs in 4IR will require higher faculties of cognitive ability, reasoning, creativity, decision making, and tech savviness (Frey and Osborne, 2017; Centre for the New Economy and Society, 2018; and Gatune and de Boer, 2019). These qualities, in most cases, come with higher levels of education.

4.7. Summary

The purpose of this chapter was to establish a link between organisational structure, division of labour and classification of occupations, and the education level (NQF level) expected per group of occupation, specifically with respect to mining production backward linkage envelope. The link between the education bands, NQF levels, qualifications and skills level in South Africa was demonstrated in Table 4-4. With the

link established a view was then taken on the probable impact of 4IR technologies on the occupations in the mining production backward linkage envelope.

It is worth noting that as the world changed and societal needs became complex, the structure of companies or organisations had to change in their endeavours to satisfy these needs. Originally organisations were structured around crafts or trades with simple unitary structures. In the pre-industrial era, the biggest organised structures in Europe were churches, the state and the military, with the military mostly employing the M-structure to effect control over a geographically dispersed legions, as it was the case with the Roman Empire.

At the dawn of the industrial era, organisations started adopting multi-unit structures in the form of the M-structure with owners or capitalists being higher in the organisational hierarchy and craftsmen and general labourers being lower in the hierarchy. Inherent in the M-structure was the division of labour, which was a lot more apparent in the manufacturing firms. The complexity of managing bigger multi-unit organisations, gave rise to the need of salaried professional managers or administrators tasked with the responsibility to plan, direct, organise and coordinate organisational activities.

With the advent of globalisation, there was a need to come up with a classification system of occupations, a task that was given to the ILO which produced ISCO-58 in 1958. The ISCO-58 was later followed by other versions. All ISCO documents consist of descriptive component of occupations and classification systems thereof. Different countries either follow ISCO classifications or have developed their own versions as is the case with South Africa which uses SASCO and OFO, both aligned to ISCO-08.

SASCO is used by Statistics South Africa for statistical reporting of labour market dynamics and OFO is used by the DoL and the DHET for labour planning purposes. Occupations classified under SASCO or OFO are underpinned by skill levels and skill specialisations. The skill level, among others, is driven by the education level an employee ought to have if he or she is to be deemed competent in an occupation. The skill specialisation on the other hand is underpinned by cognitive ability of an employee and his or her subject knowledge or knowledge of usage of specialised machines or tools. The ability to map the skill level of an occupation to an NQF qualification in South Africa, is used by the DoL and the DHET through the 21 SETAs to estimate the education and training requirement of workers (as well as prospective workers).

Of the 21 SETAs in South Africa, five namely merSETA, MQA, MICT SETA, SSETA, and ETDP SETA have developed qualification programmes that are directly linked to occupations in the mining production backward linkage envelope. In this regard, most of the qualification programmes (learnerships) offered by merSETA and the MQA are at NQF levels 2, 3 and 4 which are equivalent to OFO skill level 2 and 3. On the other hand, MICT SETA, SSETA, and ETDP SETA tend to offer qualification programmes in the mining production backward linkage envelope at NQF level 5 and higher (equivalent to OFO level 4). Organisations with elementary occupations tend to offer in-house or on-the-job training for such occupations.

Most occupations, including those in the mining production backward linkage envelope, will be disrupted by 4IR technologies in that tasks therein will be computerised to varying degrees. Occupations at OFO skill 1, 2 and 3 stand the

highest risk of being computerised thereby forcing incumbents to acquire higher cognitive and decision-making abilities, as well as creativity. These qualities in a workplace, are associated with higher levels of education.

To be able to determine the effects of 4IR on occupations in the mining production backward linkage envelope in South Africa and to fulfil the objectives of this thesis, it was necessary to gather relevant data. This was achieved by following a methodology outlined in Chapter 5.

5. Methodology and data description

5.1. Introduction

To achieve the research objectives, company related data was sourced from the Electra Mining 2016 booklet, company websites, mining magazines, MQA and LinkedIn. Data from these sources were compiled under three broad themes, namely goods and services provided by companies, location from where these companies operate, and employee related data.

5.2. Methodology

This research is empirical and it followed quantitative analysis paradigm where the primary philosophical thrust is to explain the nature of variables involved subject to the research objectives stated in Section 1.4. A quantitative analysis approach is generally associated with mathematical manipulation of data collected; in this case it is data with respect to mining production supplier companies (as defined in Definitions).

From the data collected, it was prudent to divide mining input technology into 12 technology nodes as shown in Table 5-1 in order to demonstrate the spread of mining input technology and concentration of mining production supplier companies in South Africa. Once data was categorised according to the 12 nodes in Table 5-1, it was analysed with the aim of answering research questions in Section 1.5 in line with research objectives.

Table 5-1: Twelve nodes of mining input technology (adapted from Leeuw and Mtegha, 2016).

	Class 1	Class 2	Class 3
Artefact Technology Type	**Single Artefacts** (node 1) *e.g. mine pole; integrated drill steel; shank*	**Complex Artefacts** (node 2) *e.g. roofbolt; drill bit; idler*	**Chemicals** (node 3) *e.g. explosives; oil; battery*
Machine Technology Type	**Manual** (node 4) *e.g. operator dependent machine*	**Automatic** (node 5) *e.g. equipment with automated functions*	**Autonomous** (node 6) *e.g. driverless/operator-less autonomous equipment*
Software Technology Type	**Electronic & Electrical devices** (node 7) *e.g. sensors; theodolite; blasting box*	**Monitoring & Control Software** (node 8)	**Planning & Design Software** (node 9)
Mining Services Technology Type	**Engineering Services** (node 10) *e.g. vehicle service & maintenance; training; installations*	**Mining Services** (node 11) *e.g. drilling & blasting; development; sweeping & vamping*	**Mining Engineering Services** (node 12) *e.g. mine design; process optimisation; feasibility studies*

5.2.1. Research approach

As aforementioned, this thesis followed the quantitative analysis approach as opposed to qualitative analysis approach. The reason for this approach was the requirement imposed by the School of Mining Engineering that the thesis ought to be quantitative rather than qualitative. According to Remenyi and Money (2004; pp. 61 – 62), the statements that reflect a quantitative research approach is as follows:

- “A method that resembles that of natural sciences and thus use quantitative methods;

- The researcher is objective;
- The objective of the research is to establish general laws;
- Problems are reducible to smaller or manageable components;
- Data and researcher's values are distinct from each other and it is possible to conduct research objectively;
- Possible hypotheses are derived from scientific theories to be tested empirically;
- Only phenomenon that are observable and can be measured or counted deserve to be regarded as data;
- Testing observations is the final arbiter in theoretical disputes."

Furthermore, Remenyi and Money (2004; pp. 62) stated that the following statements reflect qualitative research approach:

- "The researcher is not objective and cannot be;
- The aim is to provide in-depth understanding of the world of the research subjects;
- Generally samples are deliberately selected for their particular criteria i.e. not random;
- Evidence collection methods that typically involve close contact between the researcher and the subjects being studied;
- Evidence which is detailed, information rich and extensive;
- Analysis that is generally open to emergent concepts and ideas."

5.3. Sources of data

Data for the research was obtained from the MQA, LinkedIn, company websites, 2016 Electra Mining booklet (which was used solely to compile the original list of mining production supplier companies) and mining magazines. The original database of random companies from LinkedIn, company websites, 2016 Electra Mining booklet and mining magazines that fall within the scope of the research was compiled. Data from MQA was handled differently in the sense that only companies falling within the scope of this thesis were considered. From the original database, companies which the relevant data could not be found or did not conform to the selection criteria were excluded; the resultant was the second database comprising of 123 companies. The criteria used for compiling a list of companies within the sample was as follows:

- A company must be a mining production supplier company;
- Such companies must be registered in South Africa or the locally trading subsidiary thereof must be registered as a company in South Africa; and
- Such companies must directly supply mines in South Africa with goods and services.

It was necessary to estimate a population of mining production supplier companies in the mining production backward linkage envelope in order to estimate the sample size. To this effect, Cochran (Equation 5.1) and Yamane (Equation 5.2) were used to determine the appropriate sample size (Israel, 1992).

$$n_0 = \frac{Z^2 pq}{e^2} \quad (Equation\ 5.1)$$

$$n = \frac{N}{1 + Ne^2} \quad (Equation\ 5.2)$$

Where n_0 and n are sample size; Z is the abscissa that cuts the normal curve at α (where 1-α is equivalent to confidence level); p is degrees variability of the data attributes; q is equal to 1-p; e is the desired level of precision; and N is the population size. Both Equation 5.1 and Equation 5.2 assume 95% confidence level and further, Equation 5.2 assumes degrees variability of 50%.

Using Equation 5.1, the estimated sample size was 96 companies when the Z value was 1.96 (this correspond to 95% confidence level) and the maximum degrees of variability of 50% was used due to the anticipated lack of homogeneity in the nature of companies in the mining production backward linkage envelope if company offerings were to be divided into 12 nodes of input technology. The precision level was taken as 90% or 0.1 because the size of the population was unknown and there are no reliable published studies for comparison or used for estimation[23].

However, it was necessary to assume a population size for Equation 5.2. To this effect, a population size of 5 000[24] companies was assumed, and this resulted in a sample size of 98 companies. The precision level in Equation 5.2 was also kept at 0.1.

To improve the reliability of the outcome, the sample size as determined by Equation 5.2 (the larger of the two) was increased by 25% to 122.5 companies. In the end, a

[23] The reference in this case is mining production supplier companies.

[24] It is likely that the number of companies in the South African mining backward linkage, as demarcated in this thesis, is less than 5 000, but a population size of less than 5 000 would have yielded a smaller sample size that would most likely result in an unreliable outcome.

database of 123 companies employing 33 740 employees was compiled as shown in Table 5.2. Services and goods provided or produced by these companies were typified and classified according to the 12 nodes of mining input technologies. The typification and classification of the mining input technologies or in this case goods and services was based on the 7th edition of the South African Standard Industrial Classification (SIC) code (Statistics South Africa, 2012b) as shown in Table 5-3.

Table 5-2: Incidents of economic activity based on the SIC Code in the sample of companies supplying goods and services to mines in South Africa.

Company	SIC Codes Assigned to Technology Nodes											
	1	2	3	4	5	6	7	8	9	10	11	12
Consulting A												7110
Consulting B												7110
Consulting C										7110; 8549		
Consulting D										7110		7490
Consulting E										0990		
Consulting F												7110
Consulting G											0510	7110
Consulting H												7110
Consulting I												7110
Consulting J												7110
Consulting K												7110
Consulting L												7110
Distributor - General A							4731					
Distributor - General B	4763									3320; 3312		
Distributor - Machine A					4742					3312		
Distributor - Machine B	3290; 4763			4742; 3290	4742			4731		3312		
Distributor - Machine C					4742					7730; 0990		

Company	SIC Codes Assigned to Technology Nodes											
	1	2	3	4	5	6	7	8	9	10	11	12
Distributor - Machine D	2811; 4763	2811; 4763		2824	2824						0990	
Distributor - Machine E	2811; 4763	2811; 4763		3290; 4742						3312		
Distributor - Machine F	2811; 4763			4742	4742			4731		3312		
Distributor - Machine G	2811; 4763	4763		3290; 4742	4742			4731		3312		
Distributor - Software A							4731	4731		6202		
Distributor - Software B								4731		8549; 6202		
Distributor - Software C								4731	4731	6202; 8549		7110
Distributor - Software D								4731	4731	6202; 8549		7110
Distributor - Software E								4731	4731	6202; 8549		7110
Distributor - Software F								4731	4731	6202; 8549		7110
Distributors - Machine H	4763	4763		3290; 4742	4742					3312		7110
Distributors - Software G								4731	4731	6202; 8549		
Distributors - Software H								4731		6202		
Education Institution A										8549	8549	
Education Institution B											8549	7490; 8549
Engineering Service A										3312		
Engineering Service B				4742						3312		
Engineering Service C										3312		
Engineering Service E	4763	4763								7490		
Engineering Service F										3312		
Engineering Service G										3312		
Engineering Services H										3312		
Engineering Services I										0990		
Engineering Services J										7490		
Engineering Services K		3290					4731			3312; 3320		
Engineering Services L										3312		

Company	SIC Codes Assigned to Technology Nodes											
	1	2	3	4	5	6	7	8	9	10	11	12
EPCM A										7110		
Fuel Depot A		4763										
Fuel Depot B		4763										
Industry Organisation A											0990	
Industry Organisation B											7490	
Industry Organisation C											7490	
Manufacturer A			2011								0990	
Manufacturer B			2720							3312		
Manufacturer C			2029				2630		6201	6202		
Manufacturer D			2029				3290		3290			7110
Manufacturer E		2811										
Manufacturer F	1399; 1520; 2220											
Manufacturer G			2011							0990	0990	
Manufacturer H	4763	2811								7490		
Manufacturer I		2811								3312		
Manufacturer J			2029				4731		4731	6202		
Manufacturer K	2599											
Manufacturer L	2211											
Manufacturer M			2029								0990	
Mining Contractor A										7110	0990	7110
Mining Contractor AA											0990	
Mining Contractor B											0990	
Mining Contractor C											0990; 0990	7110
Mining Contractor D											0990	
Mining Contractor E											0990	
Mining Contractor F											0990	

Company	SIC Codes Assigned to Technology Nodes											
	1	2	3	4	5	6	7	8	9	10	11	12
Mining Contractor G											0990	
Mining Contractor H											0990	
Mining Contractor I										3312	0990	
Mining Contractor J										3312	0990	
Mining Contractor K												7110
Mining Contractor L											0990	
Mining Contractor M											0990	
Mining Contractor N											0990	
Mining Contractor O										3312	0990	
Mining Contractor P											0990	
Mining Contractor Q											0990	
Mining Contractor R											0990	
Mining Contractor S											0990	
Mining Contractor T											0990	
Mining Contractor U											0990	
Mining Contractor V											0990	
Mining Contractor W											0990	
Mining Contractor X											0990	
Mining Contractor Y											0990	
Mining Contractor Z												7110
OEM A	3290; 4763	2811; 4763		2824; 3290; 4742	4742					3312		
OEM B							2630; 4731	6201		3312		
OEM C		2651; 4742								3313		
OEM D							2630; 4731					
OEM E	2599	2599		2824; 3290						3312		
OEM F							2630					

Company	SIC Codes Assigned to Technology Nodes											
	1	2	3	4	5	6	7	8	9	10	11	12
OEM G	2599	2599		2813; 2824						3312	0990	
OEM G	2811				2813; 3290					3312		
OEM H	2811			2813						3312; 3320; 8549		
OEM I					3312							
OEM J							2651	6201				
OEM K			2011; 2720				3290; 2630					
Researcher A											7490	
Software Developer A								6201		8549		7110
Software Developer B								6201		6202; 8549		
Software Developer C									6201			
Software Developer D							2630					
Training Services A										8549		
Training Services B											8549	
Training Services C											8549	
Training Services D										8549		
Training Services E												8549
Training Services F										3320; 8549		
Training Services G										8549	8549	
Training Services H												8549
Training Services I											8549	
Training Services J										8549		
Training Services K										8549		
Training Services L											8549	
Training Services M											8549	
Training Services N											8549	
Training Services O										8549	8549	

Company	SIC Codes Assigned to Technology Nodes											
	1	2	3	4	5	6	7	8	9	10	11	12
Training Services P										0990; 8549		
Training Services Q										8549		

Table 5-3: Four digit SIC code (Statistics South Africa, 2012b).

Code	Description
0990	Service activities incidental to mining of minerals on a fee or contract basis
1399	Manufacture of other textiles n.e.c.*
1410	Manufacture of wearing apparel, except fur apparel
1520	Manufacture of footwear
2011	Manufacture of basic chemicals
2029	Manufacture of explosives and pyrotechnic products
2211	Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres
2220	Manufacture of plastic hoses and belts and other plastic products,
2410	Manufacture of sheet piling of steel and welded open sections of steel
2511	Manufacture of structural metal products
2599	Manufacture of other fabricated metal products n.e.c.*
2620	Manufacture of computers and peripheral equipment
2630	Manufacture of communication equipment
2651	Manufacture of measuring, testing, navigating and control equipment
2710	Manufacture of electric motors, generators, electricity distribution and control apparatus
2720	Manufacture of batteries and accumulators
2790	Manufacture of other electrical equipment, motors, fans
2811	Manufacture of engines and parts
2812	Manufacture of fluid power equipment
2813	Manufacture of other pumps, compressors, taps and valves
2814	Manufacture of bearings, gears, gearing, idlers and driving elements
2816	Manufacture of lifting and handling equipment
2824	Manufacture of machinery for mining, quarrying and construction
3011	Building of ships and floating structures
3290	Manufacture of plastics hard hats and other personal safety equipment of plastics
3290	Other manufacturing n.e.c.*
3312	Repair of machinery
3313	Repair of electronic and optical equipment
3315	Repair of transport equipment, except motor vehicles
3320	Installation of industrial machinery and equipment
4390	Other specialised construction activities
4530	Sale of motor vehicle parts and accessories
4659	Wholesale of other machinery and equipment
4731	Retail sale of computers, peripheral units, software and telecommunications
4732	Retail sale of audio and video equipment in specialised stores
4742	Other retail sale of new goods in specialised stores
4763	Other retail sale of new goods in specialised stores
6201	Computer programming activities
6202	Computer consultancy and computer facilities management activities
7410	Specialized design activities
7490	Other professional, scientific and technical activities n.e.c.*
7730	Renting and leasing of other machinery, equipment and tangible goods
8549	Other education n.e.c.*

*not elsewhere classified

5.4. Types of data

5.4.1. 2016 Electra Mining handbook and mining magazines data

The original list of companies compiled from the 2016 Electra Mining booklet and mining magazines was 263 and after applying the criteria in Section 5.3, the list was trimmed down to 158 companies. Finally, the list was reduced to 123 companies (informed by work done in Section 5.3), which hence forth is referred to as a sample. Particular data compiled from these sources was on goods and services provided by companies, location of premises, and the country of origin of the company or parent company. However, the Electra Mining booklet and mining magazines did not contain employee related information, of which it was obtained from sources discussed below. Table 5.4 lists the data and data types obtained from the different data sources.

Table 5-4: Sources of data.

Source of data	Number of companies	Comment
2016 Electra Mining Handbook & mining magazines (secondary trimmed list)	158	Identification of companies; location of work premises & country of origin
MQA	71	Location of work premises; employee data; products & services
Company website	27	Location of work premises; employee data; products & services
LinkedIn	24	Location of work premises; employee data
School of Mining Engineering (2019)	1	Location of work premises; employee data; services

5.4.2. MQA data

The MQA was approached to provide raw data related to ‘activities incidental to mining’, which in the case of this thesis would include mining production supplier companies in South Africa. Only 71 companies from the MQA list met the criteria set in Section 5.3. In addition to employee data, the MQA data contained company activities, places where business is conducted (provinces in South Africa and municipal or district areas), which further improved the reliability of the sample data. To provide confidentiality, code names such as Engineering Services A, Mining Services C, Manufacturing A and Training Services F (see Table 5-2) were used.

5.4.3. LinkedIn data

LinkedIn and MQA were used as primary sources of employee related data, that is, the number of employees per major groups of occupations and locations where respective companies operated for 24 of the 123 companies. For this purpose, it was necessary to register for a LinkedIn Premium account in order to get unlimited access to uploaded employee information. However, information on goods and services was obtained from respective company websites. The reliability of employee data was strengthened by comparing data obtained to similar company types from the MQA list, as the latter was considered authentic and reliable (MQA regularly collect such data for the purpose of Work Skill Plan undertaken by all SETAs).

5.4.4. Other sources

Company websites were also used to obtain information related to goods and services, location of business premises and employees. Consulting companies generally provide this information in their company websites. Similarly, where similarities existed, MQA data was used to strengthen the reliability of data. One data set regarding the School of Mining Engineering at the University of the Witwatersrand came from the School of Mining Engineering (2019).

5.5. Reliability of data

The MQA data was considered reliable as it was submitted by companies in the form of six-digit OFO code per employee. In this regard, the MQA data, where similarities existed, was used to strengthen the data reliability of other sources. Only seven companies were not subjected to this process as they did not exhibit any similarity with any company in the database.

5.6. Summary

The purpose of this chapter was to outline methodology followed when conducting this research and explain how data was compiled. To this effect, this research followed a positivist epistemological paradigm which largely deals with quantitative data. For this purpose, data was obtained from the MQA, company websites and LinkedIn. The most important data was that which relates to goods and services, employees' numbers per eight major groups of occupations, and location from where each company conducts business. Goods and services of the selected 123

companies were typified and classified into 12 nodes of mining input technology. The typification and classification of the 12 nodes were based on the four-digit SIC code summarised in Table 5-3. The analysis of the data gathered will be discussed in Chapter 6.

6. Analysis of data

6.1. Introduction

The data for this thesis was analysed with a view of gaining a better understanding of companies operating in the mining production backward linkage envelope. In this respect, the information sought pertained to country of origin of mining production supplier companies, types and origin of goods and services, where in South Africa mining production supplier companies operate and employee numbers per major groups of occupations.

6.2. Mining technology per node of mining input technology

The four-digit SIC code in Table 5-3 was used to typify and classify company goods and services according to technology nodes in Table 6-1. Company activity in this case related to input goods and services from the companies in the sample (see Table 5-2). It can be noticed in Table 5-2 that some companies have multiple entries, i.e., they offer multiple product types while others offer single product types. Through the SIC code, it was also possible to group companies into different types based on the main company activity.

To make sense of the data, it was necessary to determine incidents of input technology type within the sample. In this case, incident refers to a count or frequency of offerings (goods or services) per technology type under each class. That is,

technology incident served as an indication of the intensity of a particular technology, manifesting in the form of goods or services.

It can be noticed in Table 6-1, Figure 6-1 and Figure 6-2 that there are more incidents of Engineering Services (node 10) than any other incidents on one hand and on the other, there are nil (0) incidents of Autonomous Machine technology (node 6) in the sample of 123 companies. Table 6-2 gives examples of companies offering goods or providing services under each node. It should be noted that companies in Table 6-2 are not necessarily part of 123 companies in the sample because it is required by the Wits University research ethics that companies sampled in this thesis to remain anonymous.

Table 6-1: Number of incidents within the sample per node of mining input technology.

	Class 1	**Class 2**	**Class 3**
Artefacts & Chemicals Technology Type	*Single Artefacts* *(node 1)* **Incidents: 27**	*Complex Artefacts* *(node 2)* **Incidents: 19**	*Chemicals* *(node 3)* **Incidents: 9**
Machine Technology Type	*Manual* *(node 4)* **Incidents: 19**	*Automatic* *(node 5)* **Incidents: 11**	*Autonomous* *(node 6)* **Incidents: 0**
Hardware &Software Technology Type	*Hardware devices* *(node 7)* **Incidents: 16**	*Monitoring & Control Software* *(node 8)* **Incidents: 15**	*Planning & Design Software* *(node 9)* **Incidents: 9**
Mining Related Services Technology Type	*Engineering Services* *(node 10)* **Incidents: 75**	*Mining Services* *(node 11)* **Incidents: 45**	*Mining Engineering Services* *(node 12)* **Incidents: 25**

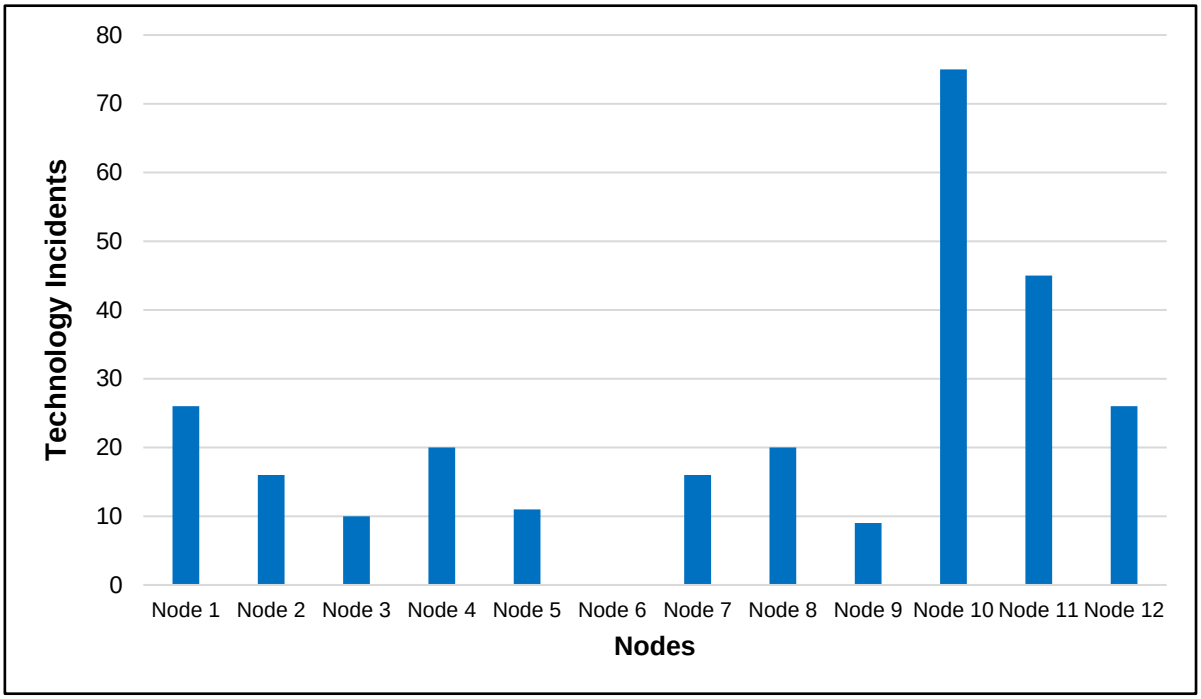


Figure 6-2: Number of technology incidents within the sample per node of mining input technology.

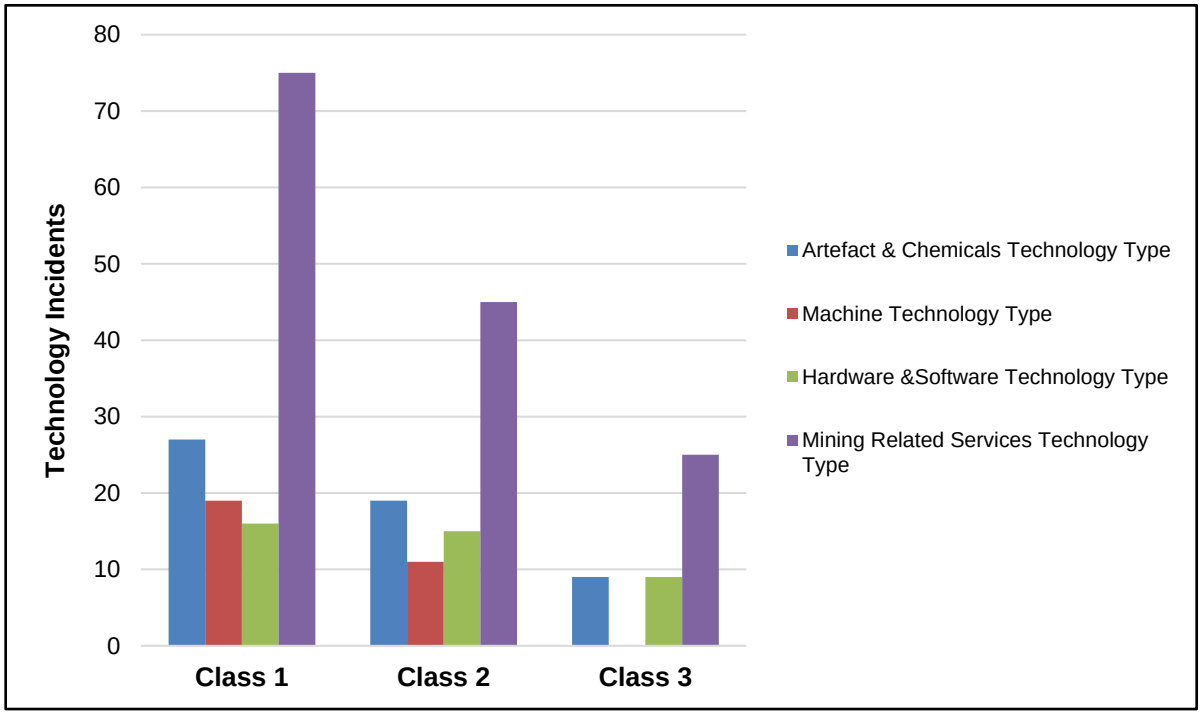


Figure 6-1: Comparison of technology incidents of classes of mining input technology.

Table 6-2: Examples of companies in South Africa providing goods and/or services under each node of technology.

	Class 1	Class 2	Class 3
Artefacts & Chemicals Technology Type	**Node 1** Barloworld Equipment & Coalseam Hydraulics and Mining	**Node 2** Aard Mining Equipment & Donaldson Filtration	**Node 3** BME & Dust-A-Side
Machine Technology Type	**Node 4** Fermel & HPE	**Node 5** Rham Equipment & Sandvik	**Node 6**
Hardware &Software Technology Type	**Node 7** DetNet & Integrated Mining Technologies	**Node 8** IMMIX Solutions & Komatsu	**Node 9** Deswik & Datamine
Mining Related Services Technology Type	**Node 10** Accutrak & Elbroc Mining Products	**Node 11** Tripple M Mining & Genrock Mining	**Node 12** Ukwazi & SRK Consulting

In Figure 6-2, it can also be observed that there are more incidents under Mining Related Services Technology type across the three classes of input technology than in any other category in the South African mining production backward linkage envelope. Furthermore, there are fewer incidents of technologies under Machine Technology type, with more incidents being in Class 1 and with no recorded incidents in Class 3.

It should, however, be noted that machinery needs maintenance and service periodically. This need gives rise to linkages between Machine Technology type and Engineering Services (node 10). In the data collected, 13 incidents out of 75 incidents in Engineering Services (Class 1) or 17.3% can be linked directly to Machine Technology type.

Machine Technology type also gives rise to incidents in Artefact & Chemicals Technology type, specifically Class 1 and 2 in the form of replacement parts or consumables. In the data collected, 22 incidents out of 27 incidents in the Single Artefacts technology (Class 1) or 81.5% and 14 incidents out of 19 incidents in the Complex Artefacts technology (Class 2) or 73.7% can be linked directly to Machine Technology type. In addition, 24 incidents out of 45 or 53.3% in Mining Services (Class 2) can be linked directly to Machine Technology type, that is, services provided rely on machines. It can therefore be safely concluded that Machine Technology type is an important type of technology in the South African mining production backward linkage envelope as it creates opportunity for other types of technology to be supplied into the mining industry, even though by itself there seems to be very few incidents thereof in the mining production backward linkage envelope.

It can further be observed in Figure 6-2 that there are more Class 1 incidents technologies than any other class. It should be noted that, apart from Mining Related Services Technology type, the complexity of the product supplied, or the hazard associated with the product, or the level of education associated with the handling or use of the product increase with class in each category. In general, Class 1 products are less complicated, attract less risk and have relatively less ownership cost than Class 2 and Class 3 products. Similarly, the same thing can be said about Class 2 products relative to Class 3 products. This explains why in Figure 6-2 there are more incidents of Class 1 products compared to Class 2 and Class 3 or more Class 2 products compared to Class 3 products.

With respect to Mining Related Services Technology type, the classes were arranged according to their proximity to the Mining Engineering discipline, with Class 3 being exclusively mining engineering services, Class 2 being mining related services that do not necessarily require mining engineering qualifications or equivalent qualifications and Class 1 being services offered to mining by other disciplines. In light of the above classification, it would appear in Figure 6-2 that mining is a discipline that relies significantly on inputs from other disciplines to achieve its objectives.

Another observation that can be made in Figure 6-2 is that there appears to be more incidents of provision of services than those of goods. This is in line with observations made in Section 3.6 in that the procurement value of services into the South African mining industry is increasing over time. The mining backward linkage procurement value of services relative to goods in South Africa can be observed in Figure 3-9.

6.3. Country of origin of companies

It can be observed in Figure 6-3 that in the sample used in this thesis, 103 or 83.7% of companies originate in South Africa, followed by USA with nine companies or 7.3%, Germany and Australia with four (3.3%) each, Canada with two companies (1.6%), and lastly Sweden with one company (0.8%). It should be noted that companies in Figure 6-3 are registered in South Africa. A company in this case can either be a parent company or a subsidiary.

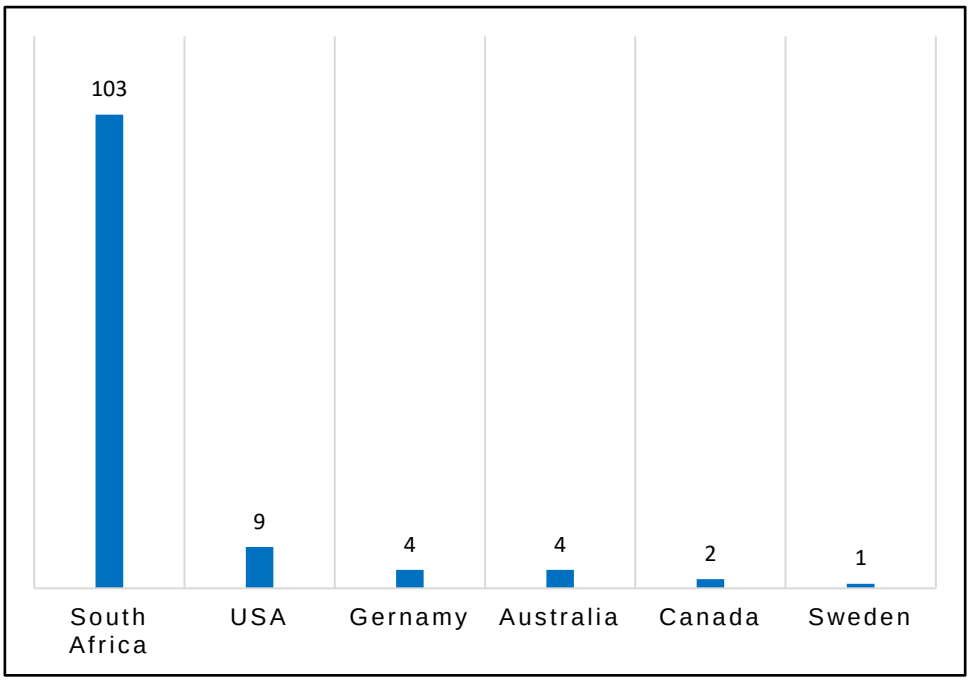


Figure 6-3: Countries from where mining production suppliers within the sample originate.

There are two things that stand out in Figure 6-3. Firstly, the results seem to suggest that South African companies benefit immensely from the procurement budget of local mines. Secondly, it appears that foreign mining production suppliers in South Africa originate from OECD countries. These are first world countries with supposedly advanced technologies than third world countries such as South Africa. It would therefore not be a farfetched notion to suggest that the South African mining industry sources expensive high technology goods from first world countries, while relying on less expensive low technology goods from the local economy.

All goods (particularly equipment), whether foreign or local, seem to be supported locally according to the results of Class 1 in Mining Related Services Technology category in Figure 6-2. It can be concluded that South Africa has adequate human resource capability to satisfy the local market with mining input services.

6.4. Country of origin of goods or services

Goods and services supplied to the South African mining industry originate from slightly more countries than those in Figure 6-3. This is because suppliers are comprised of OEMs, distributors and service providers. According to the SIC code, manufacturing companies and service providers offer goods and services that originate in South Africa. Distributors on the other hand offer local and imported goods to the local mines.

However, this distinction is not as clear cut as described above. For example, in this thesis OEMs (identified through SIC code) are local companies or subsidiaries of international companies with manufacturing facilities in South Africa. Over and above manufacturing, OEMs in some instances act as distributors for other foreign OEMs or their parent companies. This is the case with OEM A in Table 5-2. This particular company manufactures mining equipment in South Africa, while at the same time is a distributor of other international brands. In addition, OEM A maintains and services equipment (all brands) it supplies to the South African mining industry. Therefore, OEM A is a manufacturer, distributor and service provider.

Some companies undertake simple commercial structures while others undertake complex commercial structures. For example, Consultancy A in Table 5-2 only provides mining engineering consulting services (Class 3 in Mining Related Services Technology type), while OEM A has a commercial structure that can be described in the following manner:

- It produces Class 1 and 2 products under Artefact & Chemicals Technology type;

- It produces Class 1 equipment under Machine Technology type;
- It distributes Class 1 equipment under Machine Technology type;
- It distributes imported Class 2 equipment under Machine Technology type;
- It rebuilds its own Class 1 equipment as well as imported Class 1 and 2 equipment it distributes under Machine Technology type; and
- It maintains and services mining equipment, i.e. Class 1 and 2 equipment under Mining Related Services Technology type.

Sections 6.4.1 to 6.4.4 describe in depth incidents of technologies in the four categories of mining input technologies. Goods and services types that fall under these four technology categories in the sample originate mainly from South Africa, Germany, USA, Sweden, Australia and Canada. It should be noted that a high number of goods and services types do not necessarily point to market share dominance or high procurement value, but merely a capability. It is possible that one or few foreign companies have a large market share in South Africa. It is also possible that imports may be speciality products with high margins than locally produced products. This being the case, and while product value and/or market share are important variables, they fall beyond the scope of this thesis and were therefore not investigated.

6.4.1. Artefacts & Chemicals Technology type

In total there were 27, 19 and 9 incidents of Class 1, Class 2 and Class 3 of Artefact & Chemicals Technology type respectively in the sample of 123 companies originating in countries shown in Figure 6-4. South Africa had 15 or 55.6%, 12 or 63.2% and 9 or 100% incidents in Class 1, 2 and 3, respectively. This implies that there is strong evidence to suggest that South Africa has manufacturing capacity to supply mines with products under Artefacts & Chemicals Technology type. The Class 1 and 2 imports under this type come mainly from Germany, USA and Sweden and some unspecified countries.

Interestingly, the incidents of Class 3 technology in this type are recorded as coming only from South Africa. Class 3 technology comprises of chemical products such as explosives and dust suppressant additives. It is customary for local and foreign companies producing this particular class of products to build factories closer to where mines are located for logistical and cost efficiency purposes. Therefore, SIC codes in Table 5-3 assigned to activities of companies producing Class 3 products in the sample of 123 companies, are those of domestic manufacturing.

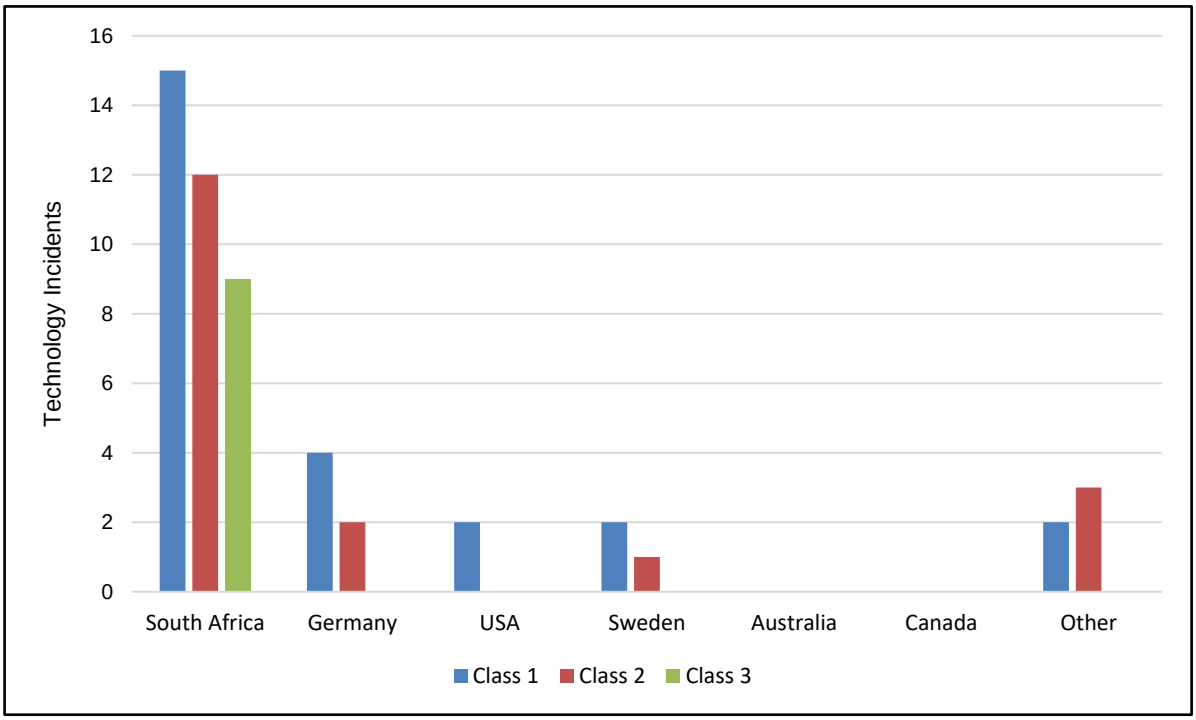


Figure 6-4: Origin of goods under Artefact & Chemical Technology type.

6.4.2. Machine Technology type

In total there were 19 and 11 incidents of Class 1 and 2 of machine technologies, respectively, in the sample of 123 companies originating in countries shown in Figure 6-5. South Africa had 12 or 63.2% and 4 or 36.4% incidents of Class 1 and 2, respectively. This implies that South Africa has home-grown capability to supply the bulk of Class 1 machines to the local market with the balance being imports. With respect to Class 2, South Africa appears not to have sufficient home-grown capability to supply the local market with associated machines, therefore the country relies on imports. In this respect, countries of importance are USA, Germany, Sweden and other countries (a guess would be China among others, although it is not explicit in

the data collected). It should be noted that a machine in the case of this thesis is a general term that includes pumps, mining vehicles and fans, among others.

Within the sample of 123 companies, there was no evidence of Class 3 under Machine Technology type. Class 3 products are autonomous products capable of making decisions within their operating sphere without the involvement of humans. The highest level of technology found to be present in this category was Class 2 which involves machines with automated processes. Class 1 products on the other hand are manually operated machines.

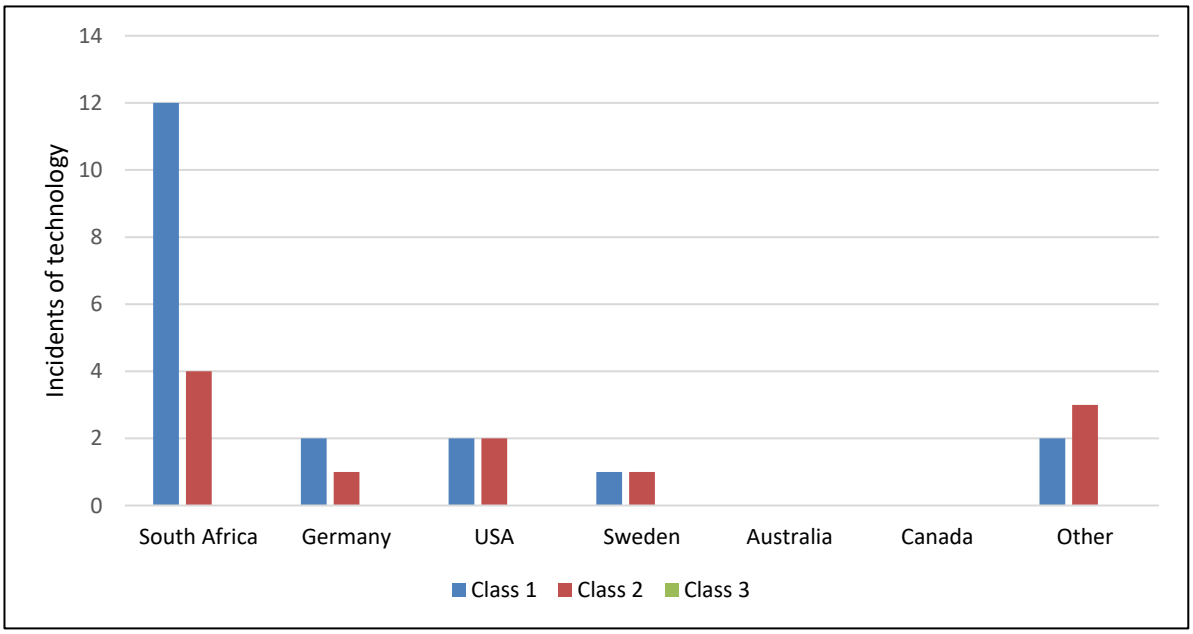


Figure 6-5: Origin of goods under Machine Technology type.

6.4.3. Hardware & Software Technology type

In total there were 16, 15 and 9 incidents of Class 1, 2 and 3, respectively of electrical and electronic hardware and software technologies in the sample of 123 companies originating in countries shown in Figure 6-6. South Africa had 10 or 62.5%, 4 or 26.7%

and 3 or 33.3% technology incidents in Class 1, 2 and 3, respectively. This implies that South Africa potentially has manufacturing capability to supply its local market with Class 1 products (electrical and electronic hardware) and the balance being imports from a number of countries around the world.

With respect to Class 2 (mine process monitoring and control software) and Class 3 (mine planning and design software), there is a high likelihood that South Africa is reliant on imported products. This could mean that there is an underdeveloped software development and programming capability in the South African mining production backward linkage envelope.

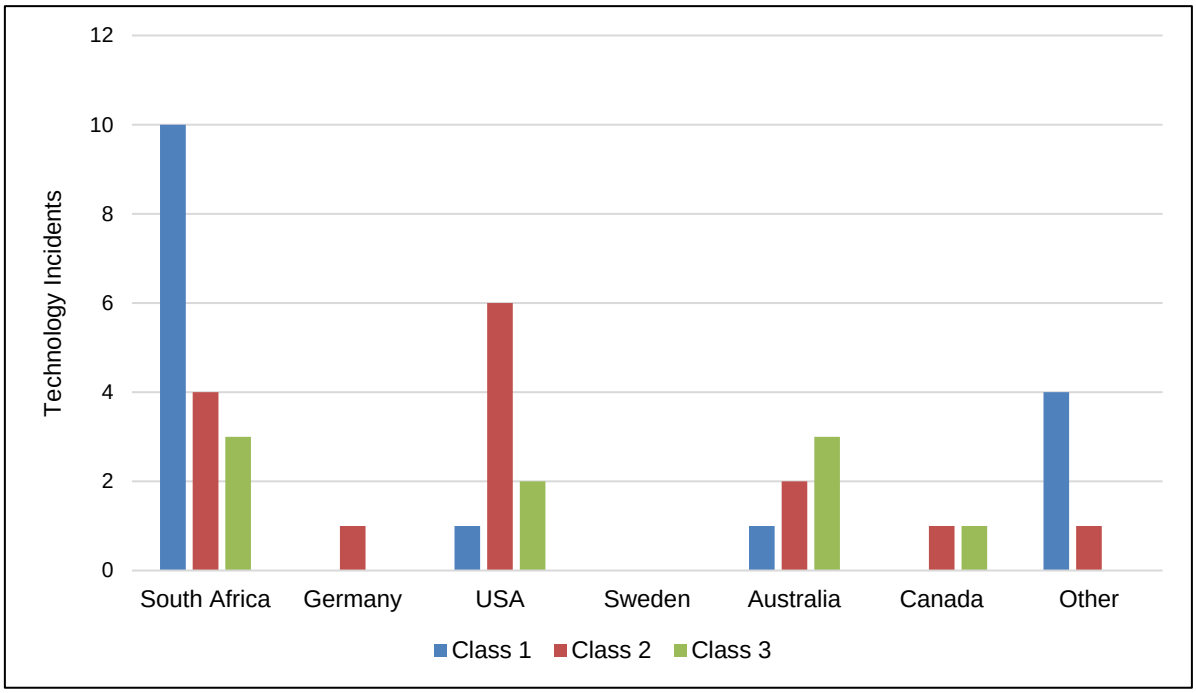


Figure 6-6: Origin of goods under Hardware & Software Technology type.

6.4.4. Mining Related Services Technology type

In total there were 75, 45 and 25 incidents of Class 1, 2 and 3 of mining related services technologies, respectively, in the sample of 123 companies originating in countries shown in Figure 6-7. South Africa had 74 or 98.7%, 45 or 100% and 25 or 100% incidents of technologies of Class 1, 2 and 3, respectively.

Services are deemed to be provided and managed by entities (local companies and/or subsidiaries of local and foreign companies) registered locally, except in one incident in Class 1 where it was explicitly evident that the services were provided locally (in South Africa) by a USA-based company. With this logic, it is not surprising that the Mining Related Services Technology type is dominated by South African based companies.

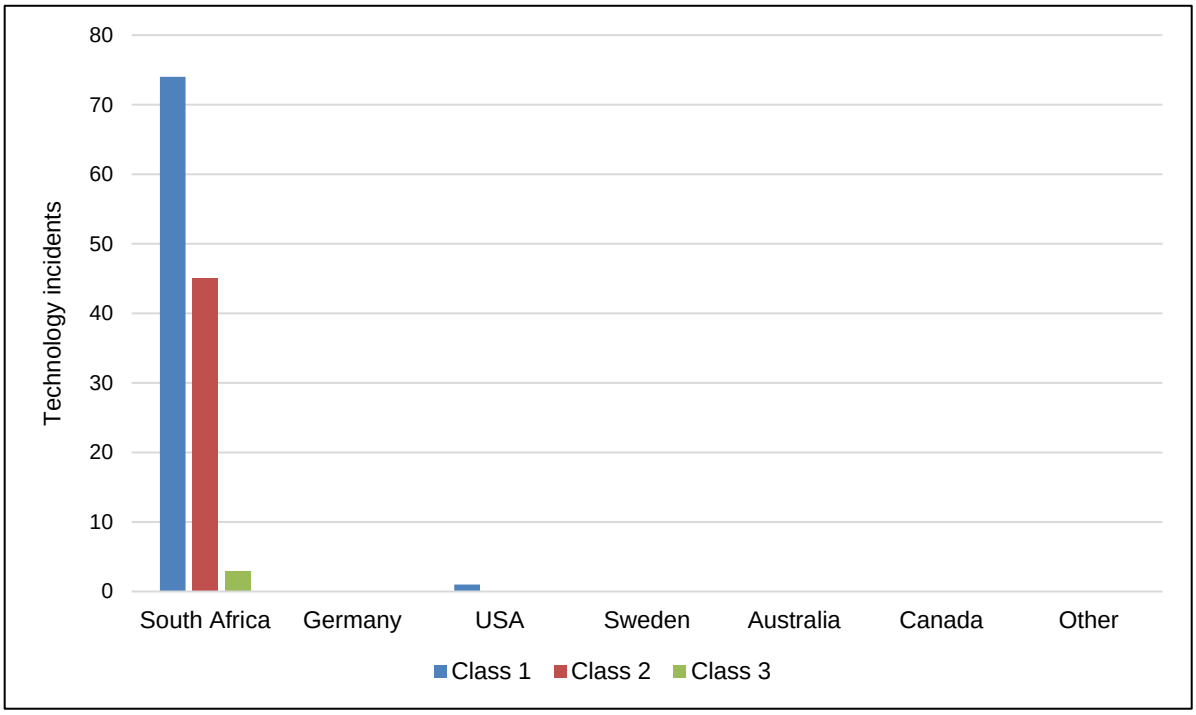


Figure 6-7: Origin of services under Mining Related Services Technology type.

6.5. Operations per province in South Africa

The analysis of the data has shown that companies in the sample vary from having a single operation to multiple operations in different provinces. South Africa has nine provinces and as indicated in Figure 6-8, the majority of operations (64.2%) are in the Gauteng Province. It should also be noted that the majority of manufacturing facilities are in the Gauteng Province, while services operations are found in the Gauteng Province and mining provinces such as Limpopo, Mpumalanga, North West, Northern Cape and Free State.

While operations are scattered around South Africa, locations of head offices of companies in the sample are concentrated in the Gauteng Province as shown in Figure 6-9[25]. It can be noticed in Figure 6-9 that 78 out of 123 companies have their head offices located in the Gauteng Province (indicated in red colour in Figure 6-9), with 18 head offices located in Johannesburg.

If metropolitan areas of the Gauteng Province are taken into consideration, then 28 head offices are located in the City of Johannesburg Metropolitan Municipality (Johannesburg, Sandton and Midrand), 27 head offices are located in the City of Ekurhuleni Metropolitan Municipality (Germiston, Kempton Park, Boksburg, Springs, Bedford, Modderfontein and Lethabo) and 12 head offices are located in the City of Tshwane Metropolitan Municipality (Pretoria and Centurion). The balance that make up 78 is in other non-metropolitan towns of the Gauteng Province. The metropolitan municipalities of Johannesburg, Ekurhuleni and Tshwane are located on the central,

[25] Colours in Figure 6-8 correspond to colours in Figure 6-9. That is, cities/towns are given colours of provinces in which they are located.

eastern and northern parts of the Gauteng Province, respectively. Most of the mines in the Gauteng Province are located on the western side (see Figure 6-10) and this is in line with the notion expressed in Section 3.2 that mines tend to crowd out manufacturing and related activities.

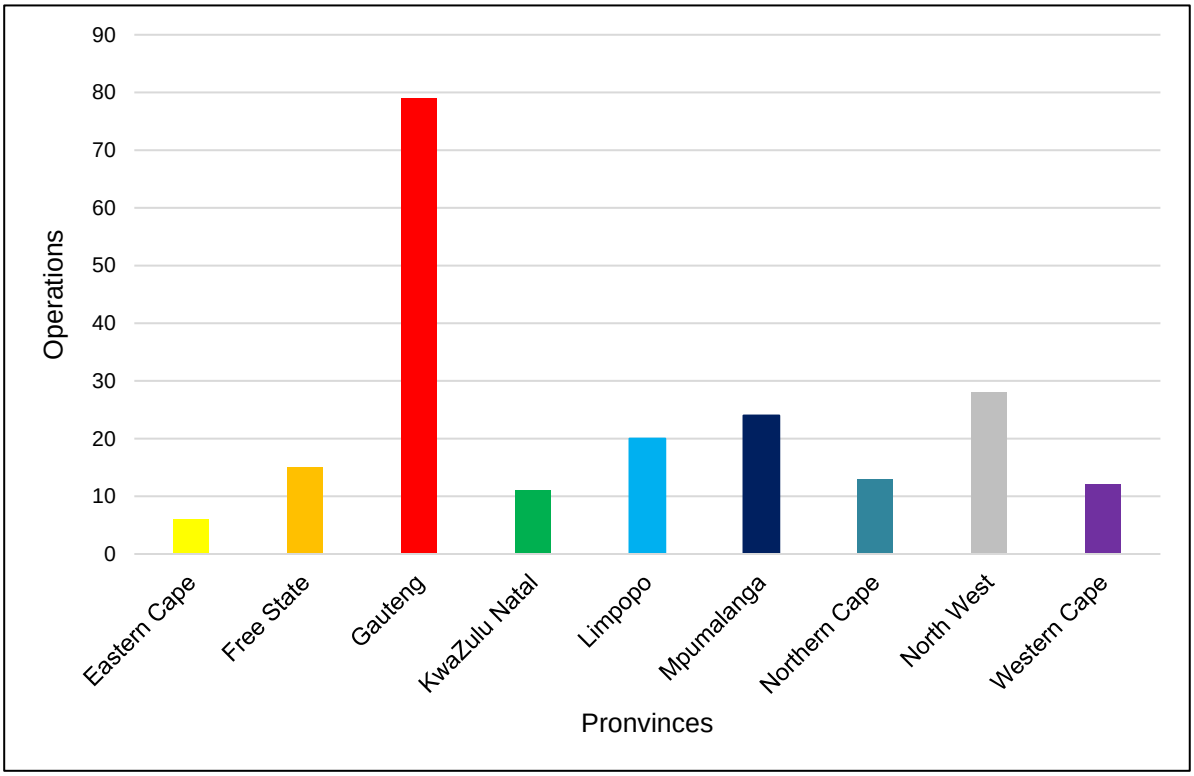


Figure 6-8: Number of operations per province in South Africa.

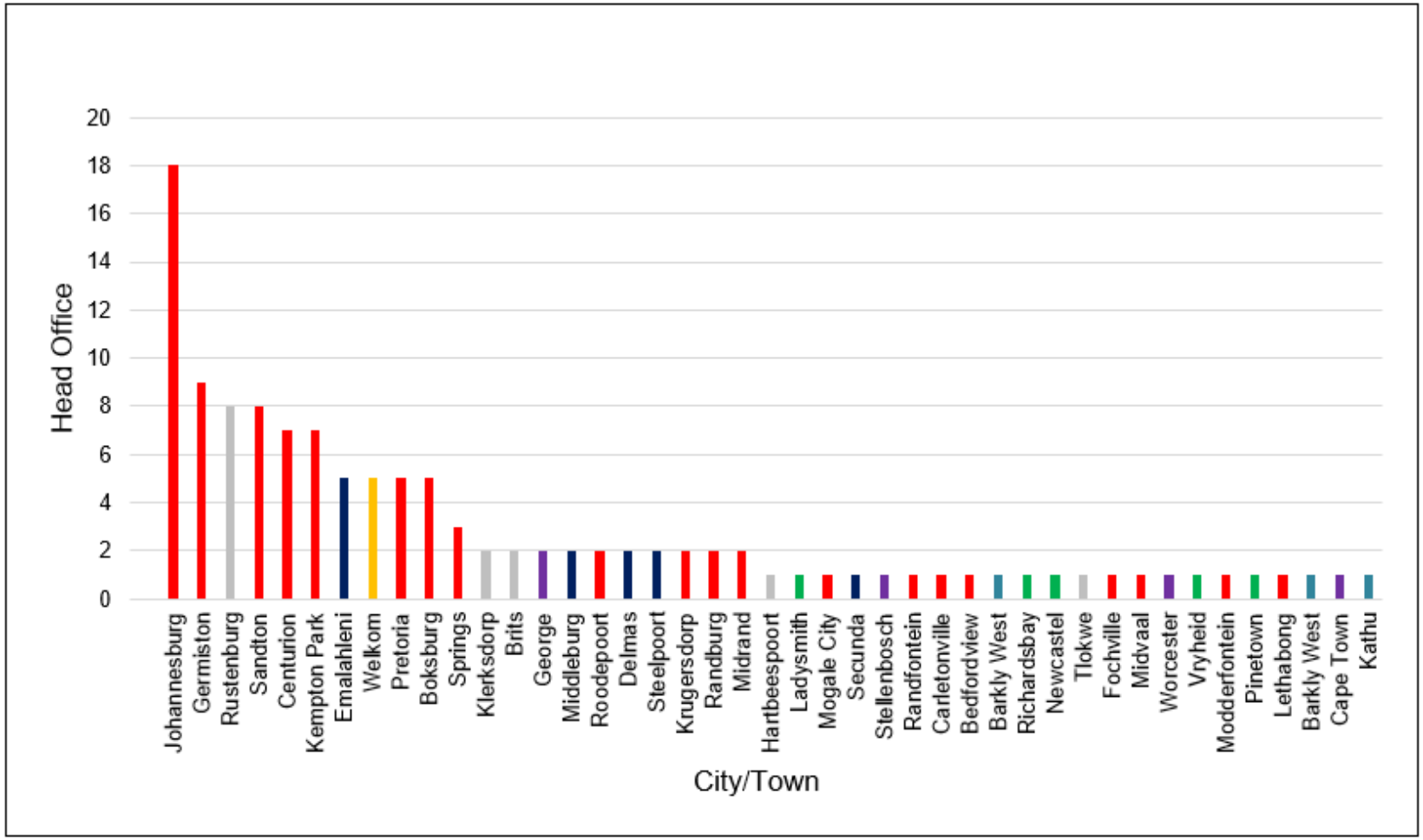


Figure 6-9: Locations in South Africa of head offices of companies the sample.

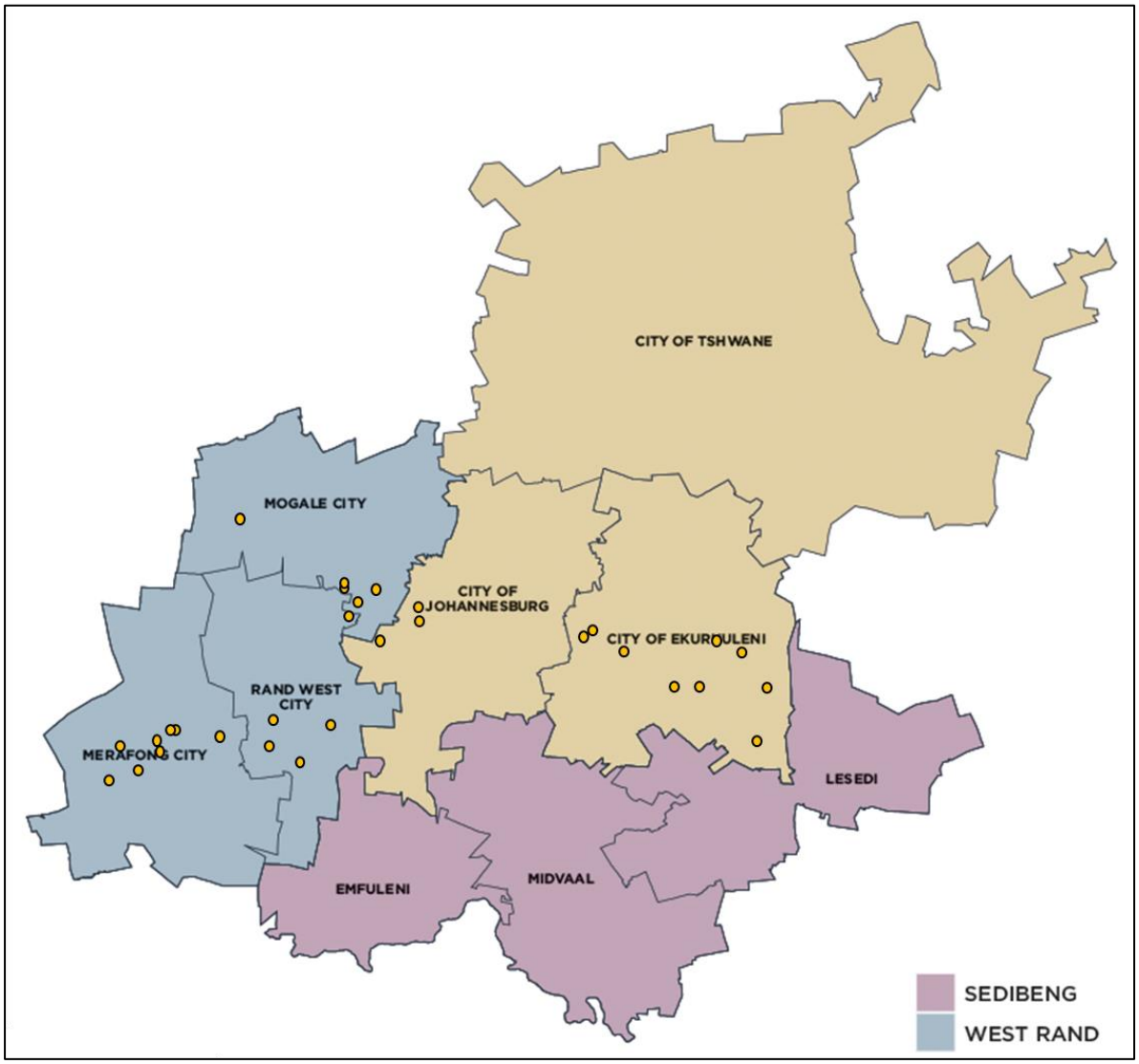


Figure 6-10: Location of gold mines in Gauteng Province[26]

[26] Sources of information: http://www.geoscience.org.za and https://municipalities.co.za/.

6.6. Employees in the mining production backward linkage envelope

6.6.1. Employees per company type

As mentioned above, data for this thesis was collected from 123 companies and the total number of people employed by these companies is 33 740. From Table 6-2, it can be observed that the sample is comprised of 13 different types of companies, all registered in South Africa and supply goods and services to the mines. Below is a short description of the company types:

- **Mining Contractors** - in the context of this thesis, are companies that carry out mining activities such as drilling and blasting, excavation support, loading and hauling, mine development and reclamation.

- **Industry Organisations** – include regulators, industry bodies and statutory organisations.

- **Manufacturing Companies** – are companies that produce (manufacture) goods such as chemicals, steel ropes, roofbolts, steel structures (support trusses), electrical and electronic devices, survey equipment, etc. These would be manufactured goods other than machines.

- **OEMs –** in the context of this research, are companies that produce machines such as mining vehicles and rigs, pumps, fans, and compressors.

- **Research Laboratories** – are companies that solely conduct technical research in mining, but not necessarily mining engineering related research.

- **Distributors** – are companies that sell other company's products to the mines. This also applies to subsidiaries that sell imported parent company's goods, provided they are registered as companies in South Africa.

- **Consulting Services** – are companies that undertake professional activities such as managerial, engineering and scientific consultancy to resolve their clients' problems.

- **Engineering Services** – are companies that undertake technical activities such as maintenance, service and repairs, installations and fittings.

- **Training Services** – are companies that undertake on-the-job mining related training and education.

- **EPCM (Engineering, Procurement, Construction and Management)** – these are engineering companies that undertake construction and management of projects on behalf of their clients.

- **Education Institutions** – are institutions such as TVET colleges and universities that provide formal qualifications in mining related disciplines.

- **Fuel Depots** – are suppliers of fuel to mining companies.

- **Software Developers** – are companies that develop mining related software.

There were 26 mining contractors in the sample, more than any other company type and collectively employed 19 646 employees, with an average of 755.6 employees per company. This was followed by manufacturing companies with a combined total

of 3 620 employees at an average of 278.5 employees per company and distributors with a combined total of 3 253 employees at an average of 180.7 employees per company as the three top employer types.

If companies in Table 6-3 were to be grouped into manufacturing and services companies, then the sample consisted of 25 manufacturing companies (that is manufacturing companies and OEMs) with a combined total of 5 560 employees against a combined total of 28 180 employees working for services companies. However, these totals do not reflect the actual activities conducted by employees in these companies. For example, manufacturing companies may offer services to their clients in the form of maintenance and services of equipment and distributors may rebuild equipment they sell to their clients. Rebuilding is considered as a manufacturing activity according to the SIC code. The distinction above between manufacturing and services merely describes the primary economic activity of companies in the sample.

Table 6-3: Company types and employee related data from a sample of 123 companies.

Company Type	Number of Companies	Total number of Employees	Average Number of Employees per Company
1. Mining Contractors	26	19 646	755.6
2. Manufacturing Companies	13	3 620	278.5
3. Distributors	18	3 253	180.7
4. OEMs	12	1 940	161.7
5. Training Services	17	1 437	84.5
6. Consulting Services	13	1 406	108.2
7. Industry Organisations	3	1 275	425
8. Engineering Services	11	678	61.6
9. Software Developers	4	153	39.3
10. Research Laboratories	1	132	132.0
11. Education Institutions	2	86	43.0
12. Fuel Depots	2	58	29.0
13. EPCM	1	56	56.0

6.6.2. Employees per major groups of occupations per province

The following bullets points summarise deductions with respect to mining production supplier companies' employee composition in the nine provinces of South Africa within the sample. The summary of the number of employees per province is shown in Table 6-4.

Table 6-4: Number of employees per major groups of occupations in each province within the sample.

Provinces	Major Groups of Occupations								
	1	2	3	4	5	6	7	8	Total
Eastern Cape	6	23	25	10	3	10	9	22	**108**
Free State	49	127	123	98	18	65	172	390	**1 042**
Gauteng	995	2 257	1 366	1 411	211	924	936	1 811	**9 910**
KwaZulu Natal	20	35	40	40	5	47	65	62	**314**
Limpopo	62	102	549	171	54	333	1 375	1 535	**4 181**
Mpumalanga	67	153	237	107	15	302	424	306	**1 611**
Northern Cape	43	91	110	67	4	123	358	271	**1 067**
North West	209	287	1 554	491	153	955	5 685	5 630	**14 964**
Western Cape	43	95	104	60	38	84	38	79	**542**
Total	**1 493**	**3 166**	**4 108**	**2 455**	**501**	**2 835**	**9 037**	**10 074**	**33 740**

- **Eastern Cape Province** – is the province with the least number of employees in the mining production backward linkage envelope in South Africa within the sample across all eight occupation classes, with a total of 108 employees across the board or 0.32% of the number of employees within the sample. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-11.

  Historically, this province was a labour sending region under the migration labour policy of the South African mining industry and there is very little mining

activity within the province. With the exception of government services, the province relies on finance, real estate and business services; wholesale and retail trade, and hotels and restaurants; and motor vehicle manufacturing (see Figure 3-4). Within these major economic activities, there is very little that flows into mining. Perhaps when forward linkages are considered, this province might be significant to mining because of the harbour services it provides, but this is outside the scope of this thesis.

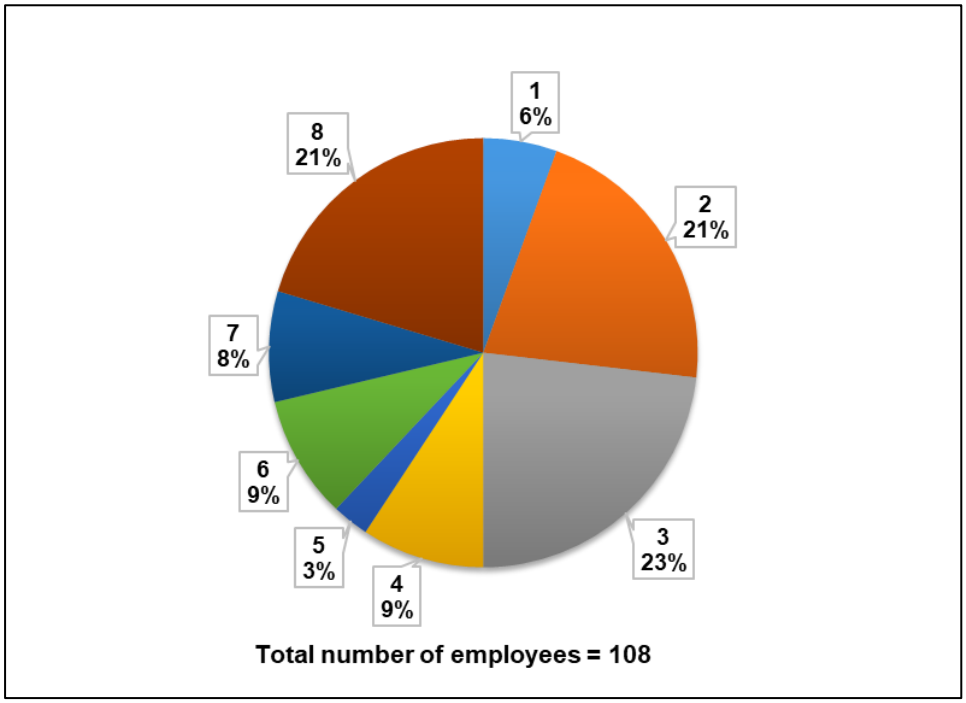


Figure 6-11: Number of employees per major groups of occupations in the Eastern Cape Province.

- **Free State Province** – is one of the provinces where mining contributes significantly to the provincial GDP. The total number of employees involved in the backward linkage within the sample was 1 042 or 3.1% of the total number of employees. While there were 390 general workers and 172 operators, it is important to note that there were 127 and 123 professionals (Major Group 2)

and technicians (Major Group 3), respectively within the province sample. These are important occupations for Mining 4.0. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-12.

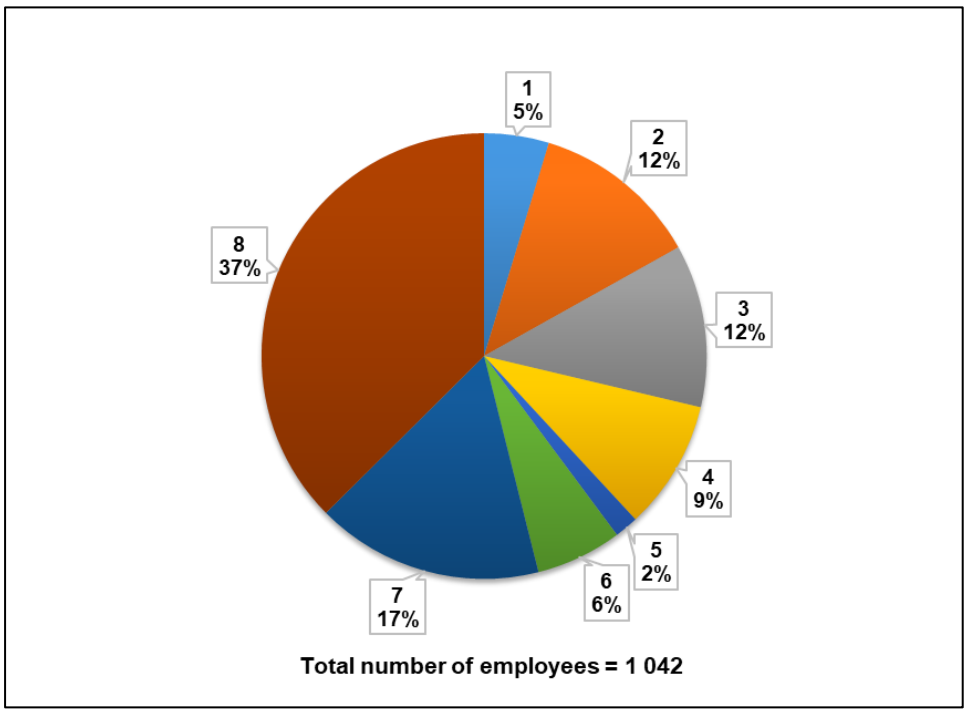


Figure 6-12: Number of employees per major groups of occupations in the Free State Province.

- **Gauteng Province** – had the second highest number of employees within the sample (9 910 or 29.4%). From Table 6-3, it can be observed that it had the highest number of managers (Major Group 1), professionals (Major Group 2) and clerks (Major Group 4). It also had the second highest number of technicians (Major Group 3), artisans (Major Group 6), operators (Major Group 7) and general workers (Major Group 8). Managers, professionals, technicians and artisans are important groups of occupations for Mining 4.0. The employee

distribution across the eight major groups of occupations in this province is shown in Figure 6-13.

It was noted in Section 6.5 that the Gauteng Province is host to the highest number of operations and head offices within the sample. It is therefore not surprising that the highest number of managers and professionals are found in this province.

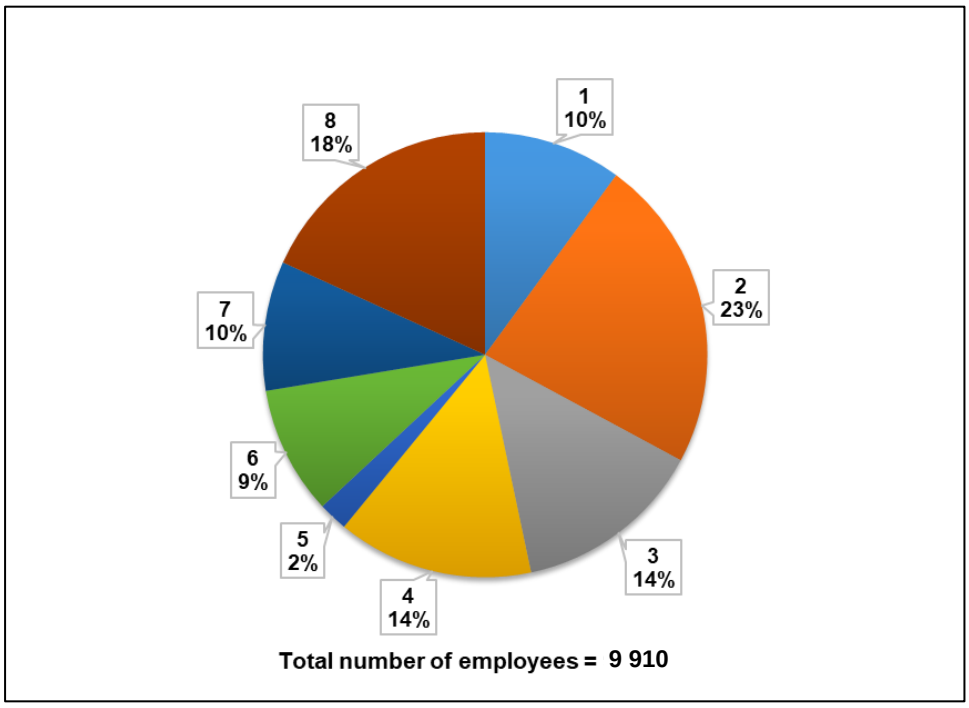


Figure 6-13: Number of employees per major groups of occupations in the Gauteng Province.

- **KwaZulu Natal** – just like the Eastern Cape Province, does not have significant mining activities. It had the second least number of employees in the mining production backward linkage envelope within the sample, with a total of 314 or 0.93% of the total. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-14.

While services and manufacturing activities are significant within the province, very little thereof flows into mining in South Africa. Like the Eastern Cape Province, harbour and transport services provided within this province fall outside the scope of this thesis.

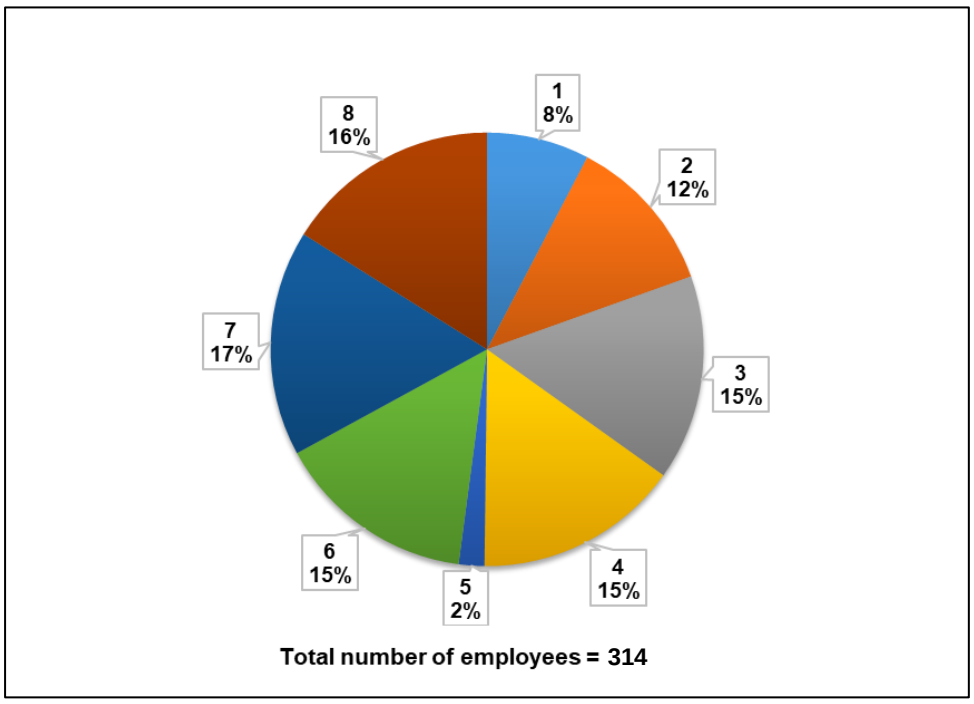


Figure 6-14: Number of employees per major groups of occupations in the KwaZulu Natal Province.

- **Limpopo Province** – is one of those provinces with significant mining activity. Within the sample, it had a total of 4 181 employees or 12.4% of 33 740, making it the province with the third highest number of employees within the sample. As mentioned above, mining crowds out manufacturing, but appears to attract mining services. This is indicated in Table 6-3 by high numbers of operators and general workers relative to other groups of occupations. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-15.

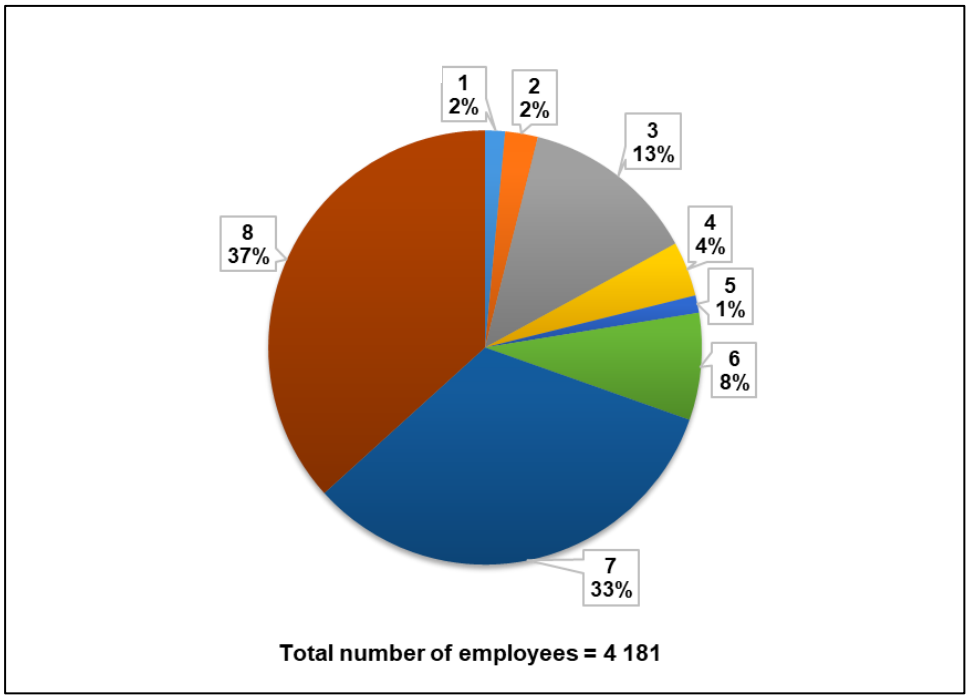


Figure 6-15: Number of employees per major groups of occupations in the Limpopo Province.

- **Mpumalanga Province** – had significant mining activities. Unlike other provinces, mining is concentrated mainly on coal mining, although there are other commodities that are mined as well. Coal mining is highly mechanised, and it is therefore not surprising that the number of people involved in the mining production backward linkage envelope within the sample in this province is 1 611 or 4.8% of 33 740. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-16.

  The high proportion of 19% of artisans relative to other groups of occupation within the province sample is another indication of high machine intensity in mining activity in this province. A 19% proportion is the highest among the

mining provinces, namely North West, Mpumalanga, Limpopo, Northern Cape, and Free State.

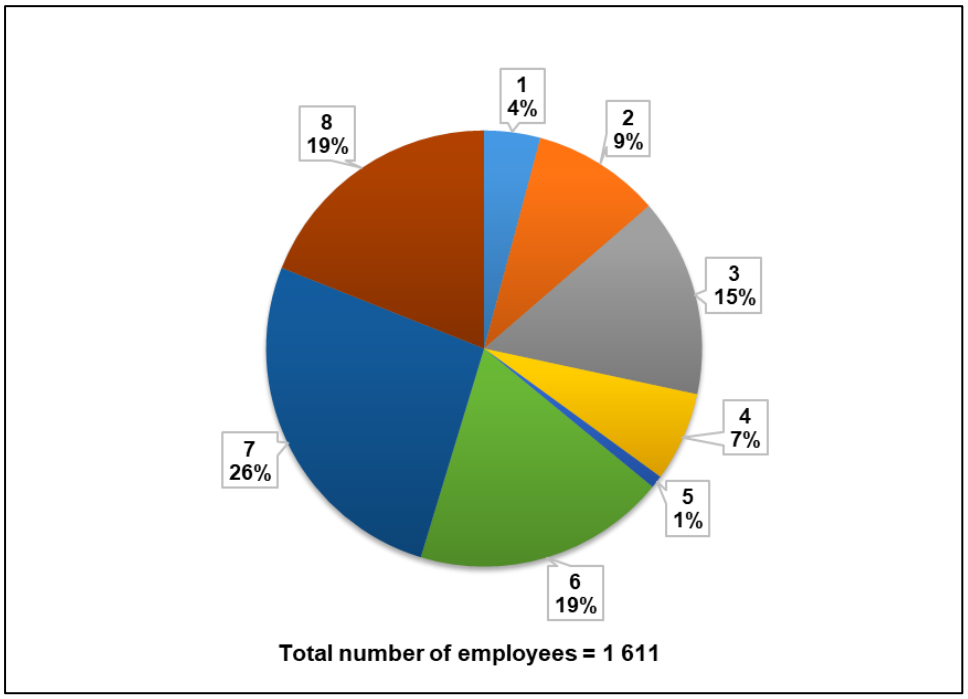


Figure 6-16: Number of employees per major groups of occupations in the Mpumalanga Province.

- **Northern Cape Province** – had a total of 1 067 or 3.2% of the total number of employees within the sample. It has a high concentration of surface mining operations and underground mining operations found therein are highly mechanised. The Major Group 6 (mainly artisans) contributed 12% (the second highest within provinces) of the total employees within the province sample. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-17.

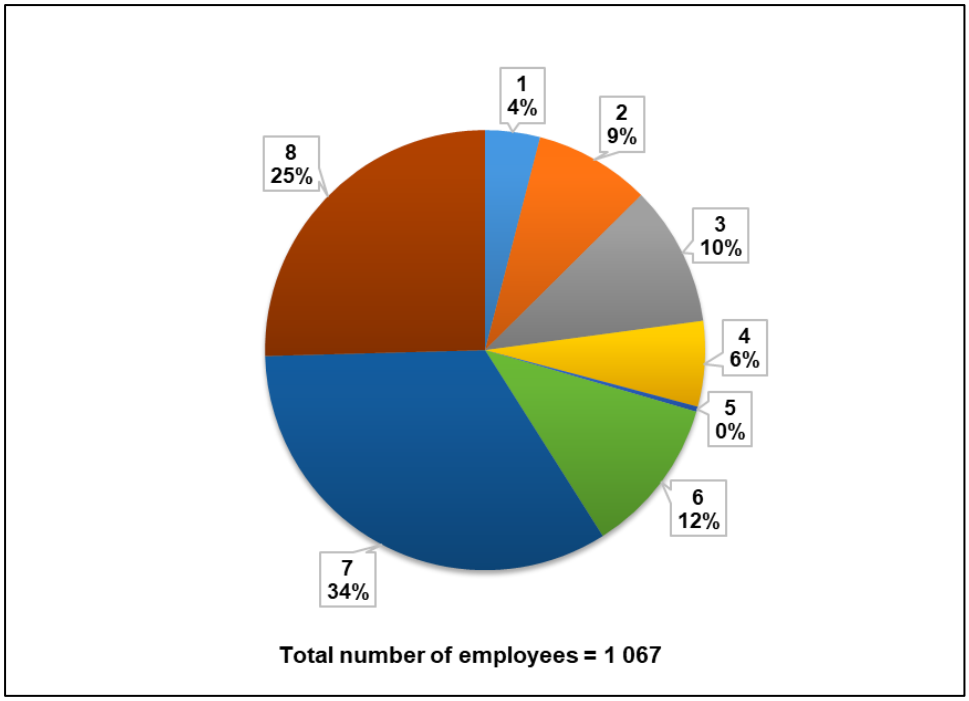


Figure 6-17: Number of employees per major groups of occupations in the Northern Cape Province.

- **North West Province** – had the highest total number of employees within the sample with a total of 14 964 employees or 44.4% of 33 740 people. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-18.

  There were 5 685 and 5 630 operators and general workers, respectively, indicating high labour-intensive activities in the mining production backward linkage envelope within the province. There are a number of narrow reef hard rock underground mines that still use conventional stope layouts that require large numbers of employees per broken tonne.

  There were 18 operations within the sample that operate in this province compared to 79 in the Gauteng Province, yet it had the highest number of employees at an average of 534.4 employees per company against 125.2

employees per company in Gauteng. Half or 50% of 28 companies operating in the North West Province were mining contractors and collectively employed 14 336 (95.8%) people of the 14 964 in the province sample.

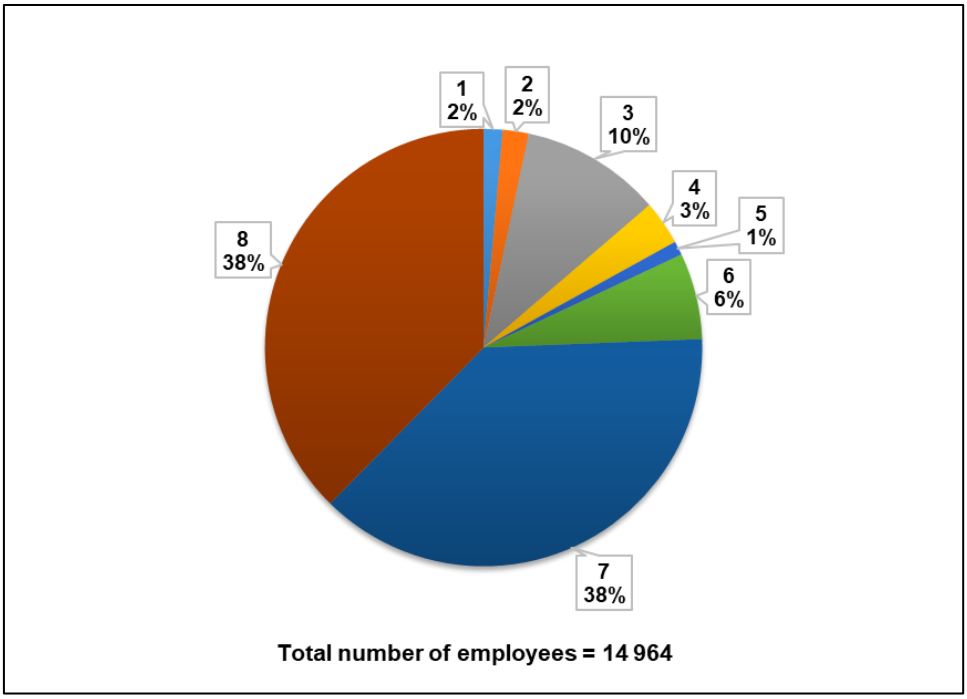


Figure 6-18: Number of employees per major groups of occupations in the North West Province.

- **Western Cape Province** – had a total of 542 or 1.6% of total employees within the sample and has insignificant mining activities. Services and manufacturing activities are significant within the province, but very little thereof flows into mining. Like Eastern Cape and KwaZulu Natal provinces, harbour and transport services provided within this province fall outside the scope of this thesis. The employee distribution across the eight major groups of occupations in this province is shown in Figure 6-19.

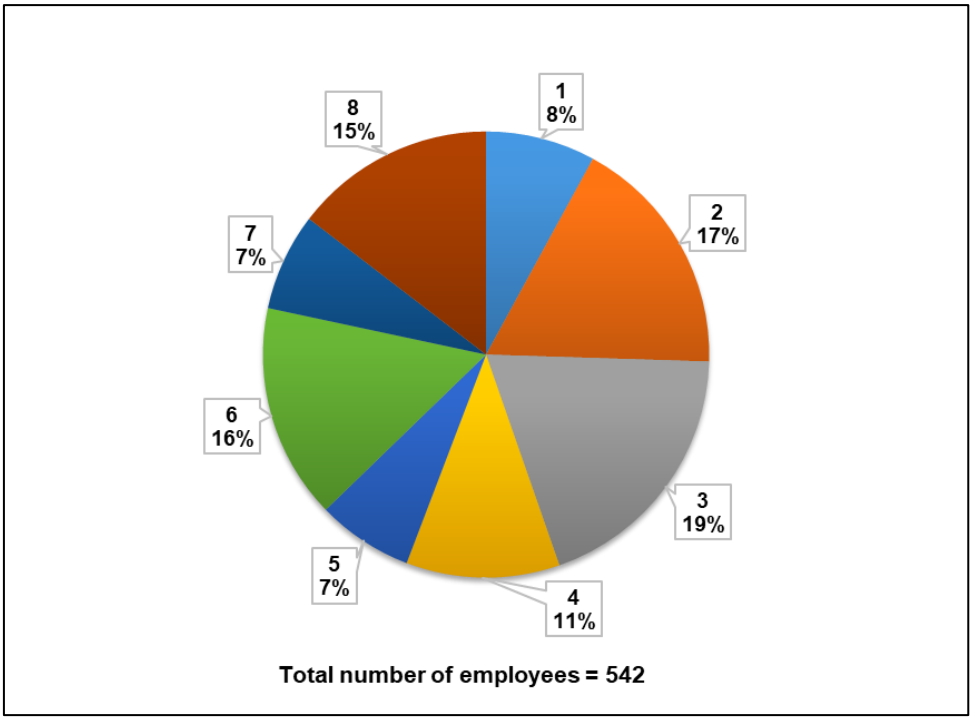


Figure 6-19: Number of employees per major groups of occupations in the Western Cape Province.

In general, according to Figure 6-20, there are more general workers (Major Group 8) and operators (Major Group 7) than any other type of group of employees in the sample. It should be noted that these two groups of occupations will be severely interrupted by technologies of Mining 4.0. Most of the employees in these two major groups of occupations have education levels that may be below the functional level for Mining 4.0 technologies. The other occupation groups that will be interrupted are Major Group 4 (clerks) and Major Group 5 (services people; mainly security and salespeople in the sample). Clerks represent 7% and service people represent only 2% of employees in the sample data.

It can be observed that there are 5%, 9% and 12% proportions of employees in Major Group 1, Major Group 2 and Major Group 3, respectively. These groups of occupations are crucial for the development, implementation, management, and

maintenance of Mining 4.0 technologies. There must be more effort to increase proportional contribution of these occupations if South Africa is to have significant local Mining 4.0 related input technologies into local mines and perhaps even for export.

Many of the employees falling under the Major Group 6 (artisans) are at risk of redundancy due to their level of education, mainly NQF level 5 or lower. However, artisans are important currently and in the future for installation, customisation, maintenance and service of hardware necessary for Mining 4.0 technologies. It may be necessary to improve the level of education in order for artisans to understand and keep up with development pace of the Mining 4.0 technologies.

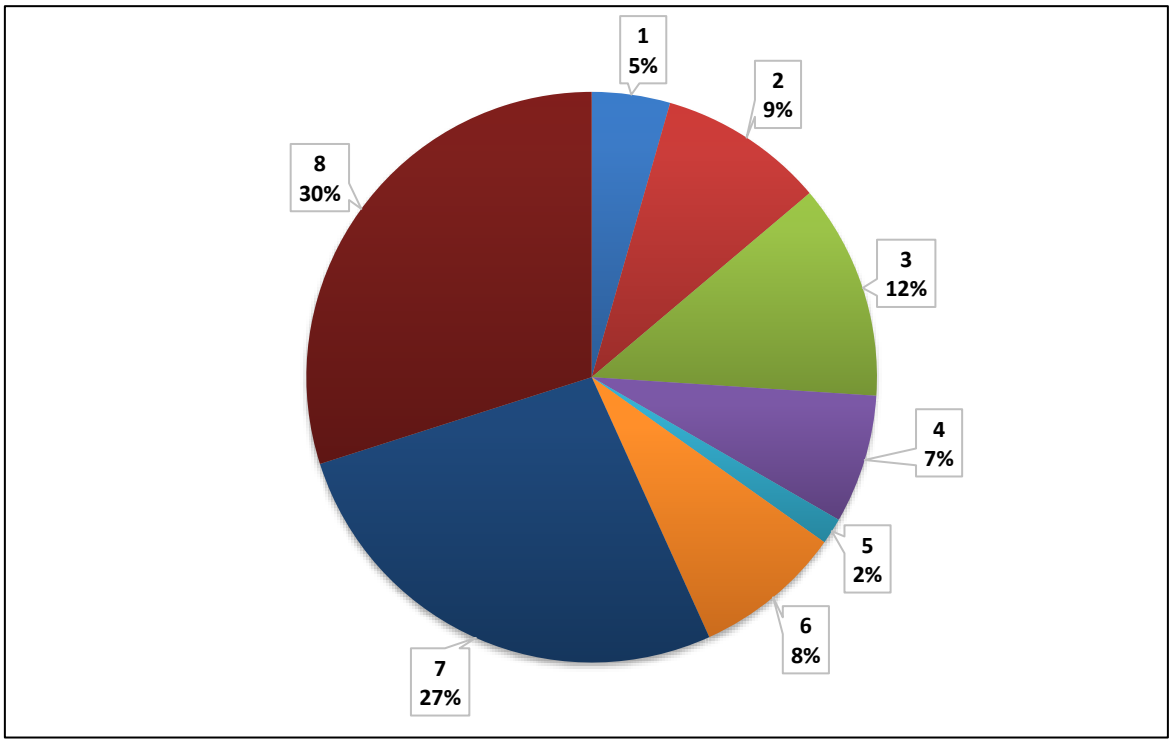


Figure 6-20: Proportion of employees per major groups of occupations in the sample of 123 companies.

6.6.3. Major groups of occupations per company type

Different company types, due to the nature of goods and services they provide, have different structures of employment with respect to major groups of occupations. The discussion below highlights these differences within the sample of companies used in this thesis. Table 6-5 gives and overview of the employee numbers per supplier company type and are shown in Table 6-6 as percentages.

Table 6-5: Summary of number of employees per major groups of occupations in the 13 company types in the sample.

Company Type	Major Groups of Occupations								
	1	2	3	4	5	6	7	8	Total
Mining Contractor	335	289	2 134	662	192	1 143	7 118	7 773	19 646
Manufacturing	177	230	452	290	22	310	1 127	1 012	3 620
Distributor	320	393	374	523	94	547	313	689	3 253
OEM	105	182	314	204	36	487	236	376	1 940
Training Service	121	784	101	182	56	75	26	92	1 437
Consulting Service	210	632	265	214	6	56	8	15	1 406
Industry Organisation	118	523	290	274	55	3	2	10	1 275
Engineering Service	64	34	78	42	5	189	143	123	678
Software Developer	19	31	36	20	1	34	4	8	153
Research Laboratory	7	2	31	15	0	0	77	0	132
Education Institution	7	51	6	9	4	0	5	4	86
Fuel Depot	4	1	5	12	30	0	3	3	58
EPCM	7	18	22	8	0	0	0	1	56

Table 6-6: Proportion of employees per major groups of occupations in each company type in the sample.

Company Type	Major Groups of Occupations							
	1	2	3	4	5	6	7	8
Mining Contractors	2%	1%	11%	3%	1%	6%	36%	40%
Manufacturing Companies	5%	6%	12%	8%	1%	9%	31%	28%
Distributors	10%	12%	11%	16%	3%	17%	10%	21%
OEMs	5%	9%	16%	11%	2%	25%	12%	19%
Training Services	8%	55%	7%	13%	4%	5%	2%	6%
Consulting Services	15%	45%	19%	15%	0%	4%	1%	1%
Industry Organisations	9%	41%	23%	21%	4%	0%	0%	1%
Engineering Services	9%	5%	12%	6%	1%	28%	21%	18%
Software Developers	12%	20%	24%	13%	1%	22%	3%	5%
Research Laboratories	5%	2%	23%	11%	0%	0%	58%	0%
Education Institutions	8%	59%	7%	10%	5%	0%	6%	5%
Fuel Depots	7%	2%	9%	21%	52%	0%	5%	5%
EPCM	13%	32%	39%	14%	0%	0%	0%	2%

- **Mining Contractors**

It can be observed in Table 6-5 that mining contractors in the sample had the highest number of operators and general workers. In Table 6-6, operators and general workers contribute 36% and 40%, respectively, to the total number of employees of mining contractors in the sample. This is followed by 11% of Major Group 3, which in the case of mining, comprises of section supervisors (miners) and shift supervisors (shift-bosses).

The nature of work performed by mining contractors in the sample can be described as labour intensive with low technology intensity. The reason for this is that narrow reef mines of North West and Limpopo provinces employ the services of mining contractors to do mining jobs similar to those of mine employees, i.e. they are used as alternatives or substitutes to mine employees. Very few of these contractors

undertake specialised work such as shaft sinking, raise boring or excavation (development) of large chambers underground.

Mining contractors largely perform mining related tasks (node 11) and undertake very little of mining engineering tasks (node 12). Mining engineers are professionals and therefore fall under Major Group 2. In Table 6-6, professionals are 1% of the total mining contractors' labour complement.

- **Manufacturing Companies**

In manufacturing, operators and general workers are 31% and 28%, respectively, of the total manufacturing employees in the sample. Unlike mining contractors, there is a higher proportion of professionals in manufacturing companies. There are also higher proportions of managers, clerks and artisans, suggesting potentially overall higher levels of work compared to mining contractors.

Some manufacturing companies also undertake contract mining (SIC code: 0990) and those that do, tend to have higher proportions of operators and general workers. The reason for this could be that in addition to manufacturing labour force, they have contract mining complements which, as discussed above, tend to be labour intensive in South Africa.

- **Distributors**

Distributors can be divided into three groups, namely (1) those that can be described as general dealers; (2) those that are focused on machines or specialised equipment; and (3) those that are focused on electrical and/or electronic hardware or software. This division is necessary as it provides a better understanding of the dynamics within

this company type. The distribution activities are denoted by SIC codes 4731, 4742 and 4763 which are codes for selling or retailing activities. Distributors of mining machines tend to undertake manufacturing activities denoted by SIC codes 2811, 2824, and 3290 and provide services (maintenance and service of machines) denoted by SIC code 3312. On the other hand, distributors of mining software tend to provide support and training activities denoted by SIC code 6202 and 8549, respectively. Software distributors also tend to provide mining engineering services denoted by SIC code 7110.

With the above, distributors offered activities that cover all 12 nodes of input technology, except for node 3 and node 6. It will be recalled that node 3 is Chemical technology, which 100% thereof in the sample is undertaken by manufacturing companies in South Africa and it would appear that they sell directly to the mines. It will also be recalled that node 6 is Autonomous Machine technology and none of the companies in the sample produced or sold this type of technology.

- **OEMs**

OEMs, similar to distributors, offer activities that cover all 12 nodes of input technology, except for nodes 3, 6 and 12. In the sample, there are 12 OEMs and 13 manufacturing companies, and the former employed 1 940 people and the latter employed 3 620 employees in the sample. This would suggest that OEMs are not as labour absorptive as manufacturing companies. This can be taken further to conjecture that manufacturing of equipment is a capital-intensive venture that uses high level of technology, which in turn is relatively less labour absorptive compared to manufacturing of artefacts (widgets). This conjecture is partially supported by lower

proportions of operators and general workers and higher proportions of professionals, technicians and artisans in OEMs compared to manufacturing companies (see Table 6-6).

- **Others**

Apart from the research laboratories with 58% of employees being operators and engineering services, the rest of the remaining company types appear to have low proportion of labour in low level jobs, nodes 6, 7 and 8 and high proportion in high level jobs namely nodes 1, 2, and 3. However, with the exception of industry organisations (in particular Industry Organisation A in Table 5-2), all other company types in the sample, except for mining contractors, manufacturing companies, distributors and OEM, tend to have relatively low employment levels.

6.7. Summary

The purpose of this chapter was to provide analysis of data gathered. In this respect, a database consisting of a sample of 123 companies was compiled. The database had a number of fields like company products (goods and services) arranged according to twelve technology nodes (a matrix of types of technologies and their class); company's country of origin; municipalities in South Africa where each company operates; and number of employees per major groups of occupations for each company in the database.

The analysis of the data showed that there were more incidents of Engineering Services (node 10) than any other node. Many companies in the sample, particularly company types such as manufacturing, distributors, OEMs, engineering services,

software developers and training service providers provide some form of engineering services to the mines.

Engineering Services were followed in second place by Mining Services (node 11), which is basically contract mining. The data suggested that South African companies are dominant locally in this space. Services in South Africa are largely executed by local people, thereby giving South Africa a competitive edge in engineering and mining services sector in the domestic mining production backward linkage envelope. On the other hand, South Africa was found to be lacking in the production of autonomous technology (node 6). This particular node deals with manufacturing and retailing or distribution of autonomous machines.

The country of origin of companies and products (goods and services) were analysed with a view to determine whether the mining production backward linkage envelope is dominated by local or foreign companies. The data in this respect showed that there were more South African companies than from any other country in the local mining production backward linkage envelope. The data with respect to the latter showed that there were more local products flowing into local mines than imported products based on technology incidents in all nodes except in nodes 6, 8 and 9. In node 6 there was a zero (0) count for all countries. In node 8 South Africa was lagging behind Australia and in node 9 there were three counts each for South Africa and the USA. The conclusion that can be drawn from the analyses of country of origin of companies and products is that there is dominant presence of South African companies and goods and services in the South African mining production backward

linkage envelope. However, this should not be mistaken to imply market share dominance or high value per unit of sale.

The rationale of looking into the number of operations per provinces and municipal areas was to establish where jobs are being created in South Africa as a result of mines' input demand. The data showed that there were more company operations and head offices in the Gauteng Province than any other provinces, more than in mining provinces such as North West, Mpumalanga and Limpopo. Furthermore, non-mining provinces such as Eastern Cape, KwaZulu Natal and Western Cape have the least number of companies.

When one focused on the Gauteng Province, it was found that Johannesburg was home to more head offices than any other city in the province, then followed by Germiston and Sandton. When that data was reconfigured to show metropolitan municipal areas, the Johannesburg Metropolitan Municipality had more head offices, followed by Ekurhuleni Metropolitan Municipality and Tshwane Metropolitan Municipality. These metropolitan areas are located in central, eastern and northern side of the Gauteng Province. Mines in the province are found predominately on the western side. This leads to a plausible conclusion that mining crowds out backward linkage companies, a phenomenon that is also observed at the provincial level.

When the companies were arranged according to company types, it was found that there were 13 different types, but overlapping in terms of goods and/or services they provide. There were more mining contractors in the sample than any other company type, followed by manufacturing companies and distributors. Mining contractors employed on average 755.6 employees per company, whereas manufacturing

companies and distributors employed on average 278.5 and 180.7 employees per company respectively.

When the number of employees per occupation group was analysed, it was established that 30% of employees in the sample were general workers (Group 8), operators (Group 7) accounted for 27% of employees in the sample, followed by technicians (Group 3) who accounted for 12%. Group 5 which consists of occupations such as security guards and sales people accounted for only 2% of employees in the sample.

It was interesting to note that, despite the Gauteng Province being a host to the highest number of companies in the sample, 44.4% of employees in the sample were from the North West Province and 95.8% of whom were employed by mining contractors. In fact, mining provinces in South Africa, namely North West, Northern Cape, Mpumalanga, Limpopo and Free State, all have high proportions of Group 8 and Group 7 employees. However, in non-mining provinces, these two groups are not visibly prominent.

The main objective of this thesis was to develop an employment estimator formula in upstream activities to mining, specifically mining production backward linkage envelope, as a result of the demand for inputs by mines in South Africa. To this effect, Chapter 7 discusses the development of the employment estimator formula.

7. Determination of the employment estimator formula

7.1. Introduction

This chapter discusses how different equations of estimating induced employment opportunities in the South African mining production backward linkage envelope (employment estimator formulae) were derived. Originally, as discussed in Chapter 6, there were 13 company types and eight major groups of occupations to be considered, but as discussed in Section 7.2, only Mining Related Services Technology type will be considered, resulting in only mining contractors and engineering services company types to be considered in the derivation of the employment estimator formulae. The derived employment estimator will have three versions, namely deterministic, stochastic and time-dependent variations.

7.2. Considerations for the employment estimator formula

The analysis of the data within the sample showed that, except for mining contractors and engineering services company types, it will be difficult to state with any certainty that a specific mining site has directly induced employment in a specific company. While there is a clear understanding that mining can induce employment in companies that supply mining goods and services as well as in companies that add value to mined goods, such inducement, except in the case of mining contractors and engineering services companies, can be described as indirect. This then makes it difficult to estimate employment opportunities a new mine can induce in such companies.

With this view, a decision was made to limit the application of the employment estimator formula to mining contractors and engineering services companies, whose induced employment was considered as direct and verified by mine data used for validation (see Section 7.6). In the sample of 123 companies, there were 26 and 11 mining contractors and engineering services companies respectively (see Table 7-1). The 26 mining contractors collectively were operational in 71 mine sites and the highest number of mining contractor employees per site was 840 and the lowest was 11. With respect to engineering services companies, the 11 companies in the sample collectively were operational in 18 mine sites with highest number of employees per site being 121 and the lowest being 8.

Table 7-1: Data related to mining contractors and engineering services companies.

Company Type	Number of Companies	Total number of Employees	Number of sites	Average Number of Employees per site
1. Mining Contractors	26	19 646	71	276.7
2. Engineering Services	11	678	18	37.7

7.3. The deterministic employment estimator formula

The deterministic equations are without randomness when estimating future states. It therefore follows that the general form of the deterministic employment estimator formular is:

$$Y = kn \ (Equation\ 7.1)$$

Where $k \geq 0$ and $n \geq 0$, Y is a number of employment opportunities, k is a constant for each company type and n is a number of companies on a mine site. Each

company type has a maximum of eight major groups of occupations as inputs in its provision of services and therefore, there will be eight major groups of occupations constants (k_{ij}) per company type.

7.3.1. The derivation of deterministic employment estimator formula

The major groups of occupations constants (k_{ij}) in Table 7-2 were derived by calculating the average number of employees in each major groups of occupations per site per company type. Thereafter a sum of k_{ij}, that is E_i, was calculated such that:

$$a_{ij} = \frac{k_{ij}}{E_i} \ (Equation\ 7.2)$$

Where a_{ij} is the employment opportunity inducement coefficients as shown in Table 7-3.

Table 7-2: Major groups of occupations constants (k_{ij}).

Company Type	Major Groups of Occupations								Sum*
	1	2	3	4	5	6	7	8	
Mining Contractors	6	5	34	10	2	15	98	106	277
Engineering Services	4	2	5	3	0	11	4	8	38

*Numbers are round off to the nearest unit.

Table 7-3: Employment opportunity inducement coefficients (a_{ij}).

Company Type	Major Groups of Occupations								Total
	1	2	3	4	5	6	7	8	
Mining Contractors	0.021	0.019	0.122	0.036	0.009	0.055	0.353	0.384	1.000
Engineering Services	0.099	0.063	0.140	0.080	0.010	0.296	0.099	0.214	1.000

The major groups of occupations constants (k_{ij}) shown in Table 7-2 can be calculated or derived by multiplying each coefficient with a row sum in Table 7-2 such that:

$$k_{ij} = a_{ij}E_i \ (Equation\ 7.3)$$

Equation 7.1 can be expanded to estimate employment opportunities per major group of occupations induced in supplier companies. To this effect, Equation 7.1 is expanded as follows:

$$Y_i = n(k_{i1} + k_{i2} + k_{i3} \dots k_{i8})$$

$$Y = \sum_{i=n}^{8} k_{ij}n \ \ (Equation\ 7.4)$$

Equation 7.4 is a vector sum of unit vectors. Considering at this stage that there are eight major groups of occupations and two company types, then Y is a function of major groups of occupations per company type and can be solved simultaneously such that Equation 7.4 is restated as follows:

$$\begin{bmatrix} k_{11} & \dots & k_{18} \\ k_{21} & \dots & k_{28} \end{bmatrix} \cdot \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} \ (Equation\ 7.5)$$

Where $K = \begin{bmatrix} k_{11} & \dots & k_{18} \\ k_{21} & \dots & k_{28} \end{bmatrix}$ is the major groups of occupations constants matrix, $X = \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$ is a vector matrix of number of company types that provided services on a mine and $Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}$ is a vector matrix of the number of employment opportunities per company type. Equation 7.5 is deterministic.

7.4. The stochastic employment estimator formula

According to Taylor and Karlin (1998, p. 2) a “deterministic model predicts a single outcome from a given set of circumstances. A stochastic model predicts a set of possible outcomes weighted by their likelihoods, or probabilities”. This being the case, it should be accepted that the requirements of each mine will be bounded by a set of unique circumstances and needs. Therefore, a deterministic model is most likely to yield unnatural solution. It is for this reason that it is imperative to develop a stochastic model of the employment estimator formula.

To develop the stochastic model, Equation 7.4 was modified by using random numbers. As stated above, the range for the total number of employees in mining contractors was from 11 to 840 with a mean of 277 (E_i), whereas the range in engineering services companies was from 8 to 121 with a mean of 38 (E_i). In this respect, the probability of employment opportunities is defined by $P\{X = x\}$, where x is the estimated number of employees per company type such that $p_{min} \leq x \leq p_{max}$, where p_{min} and p_{max}, respectively, denote lower and upper limits per company type.

In this regard, it was necessary to determine the number of sites below and above E_i. The rationale behind the determination of proportions above and below E_i was to create a conditional probability such that more weight can be given to the side of E_i where there are a greater number of operations so that the outcome is most likely not to be an over or under estimation of employment opportunities induced. For sites with the number of employees below E_i, the range was, $p_{min} \leq x \leq p_{E_i}$ for $P\{X = x\}$, and

where the number of employees were above E_i, the range was $p_{E_i+1} \leq x \leq p_{max}$ for $P\{X = x\}$. This being the case, then:

$$Y = \sum_{i=1}^{8} a_{ij} n P\{A \cap B\} \ (Equation\ 7.6)$$

In Equation 7.6, if condition A takes place, then condition B does not exist and vice versa. In the case of mining contractors, proportion of sites with number of employees equal or below E_i (condition A) was 69% and above E_i (condition B) was 31%. In the case of mining services companies, proportion of sites with number of employees equal or below E_i was 34% and above E_i was 66%.

Equation 7.6 was modelled in Microsoft Excel in the following manner:

- To find, for example, the number of Major Group 8 (Y_{i8}) employment opportunities induced under mining contractors when the intention is to use only one company, the calculations are as follows:

  $Y_{1,8} = J21 * IF(M73 =< 0.69, O73, P73) * L73,$

  where $J21 = a_{ij}$, $M73$ contains function $RAND()$, $=< 0.69$ being the probability condition, E_i, $O73$ contains function $RANDBETWEEN(11, 277)$, $P73$ contains function $RANDBETWEEN(278, 840)$ and $L73$ contains 1.

A simulation with 1000 iterations where $n = 1$ was run for both company types with the results shown in Table 7-4. It can be noticed that the estimated induced employment opportunities is between 24 and 936 with a mean of 276. The mean

value can be compared to deterministic model solution that produced and average of 315 opportunities. Interestingly, the probability of creating exactly 315 employment opportunities under stochastic conditions was 0.1%.

Table 7-4: Statistical analysis of simulated stochastic model for the employment estimator formula.

	Values
Mean	276
Minimum	24
Maximum	936
Standard deviation	216
Median	197
Mode	191
Skewness	1.28
Count	1000

7.5. Time-dependent employment estimator formula

It is difficult to estimate the impact of 4IR technologies on employment. There are few authors to date that have attempted to quantify this impact and estimations vary considerably. For example Frey and Osborne (2013) estimated that the overall risk of employment redundancy by 2030 due to automation or computerisation of tasks will be 49%. This risk was estimated to be much lower at 9% by Arntz et al. (2016) and PwC (2018) estimated the overall risk to be 30%.

The difficulty of estimation, among others, is due to variations between and within regions, countries, and sectors of the economy, with developing regions likely to be more impacted by automation than developed regions. Variations between countries is largely due to politics and regulations, business innovation, infrastructure,

affordability of technology, skills level, usage of technology by individuals, usage of technology by business, usage of technology by government, the impact of technology on the economy and the social impact of technology (Gatune and de Boer, 2019).

Notwithstanding the above, this thesis considered the work of McKinsey Global Institute (2017), the World Economic Forum (2018) and PwC (2018) when developing the growth or decay component of the employment estimator formula. The model for estimating potential adoption rate of automation in current jobs by McKinsey Global Institute (2017) was used to determine the upper and lower limits of rate of increase of automation from the base in 2016 to the year where adoption would be 50%. The McKinsey Global Institute model follow the normal S-curve shape from zero (2016) to 100% (year x). The curve from 2016 to the year x where 50% adoption was estimated through non-linear regression analysis. The resultant curve up to 50% adoption was used to develop time-dependent population decay rates corresponding to low and high adoption rates.

In the case of the high rate (upper limit) of adoption in the McKinsey Global Institute model, it took 21 years to reach the 50% adoption and 56 years in the case of low rate (lower limit). The assumption made in this thesis with respect to this model was that the automation of tasks will result in redundancy of employment, i.e. loss of employment. This being the case, it will take 21 years in high adoption rate environment to lose 50% of employment opportunities based on Equations 7.6 if those opportunities were created in 2016 and with tasks thereof depended on prevailing technology in the same year. Similarly, it will take 56 years to lose 50% of

employment opportunities under the low adoption rate environment. To this effect, the time-dependent decay rate of employment opportunities was determined as follows:

$$P(t) = P_0 e^{kt} \ (Equation\ 7.7)$$

Where k is the decay rate and t is years with $t = year\ x - 2016; year\ x \geq 2016$. P_0 is the initial job opportunities estimated through Equations 7.6, and $P(t)$ are estimated job opportunities in a particular year from 2016. This being the case, the time-dependent employment opportunities in high and low adoption rates respectively in $year\ x$ can be estimated as follows:

$$P(t)_{high} = P_0 e^{-0.0330t} \ (Equation\ 7.8)$$

$$P(t)_{low} = P_0 e^{-0.0124t} \ (Equation\ 7.9)$$

While automation is likely to reduce employment in the current occupations in general, there is consensus in the literature that new jobs or occupations will be created. The view is that in general people with degrees (e.g. professionals) or relevant post school leaving qualifications (e.g. technicians) as well as certificated people in occupations with less risk of automation will be largely shielded from job redundancy (Frey and Osborne, 2013, World Economic Forum, 2016 and Autor et al., 2019). Broadly Major Group 1, 2, and 3 and to some extent Major Group 6 will continue to be relevant and enjoy growth in the 4IR era (PwC, 2018 and World Economic Forum, 2018). Furthermore, PwC (2018) showed in Figure 7-1 rates of risk

of automation in various occupations. This information was used to compile Table 7-5 which shows adjustment variables, α and β, for Equation 7.8 and 7.9 such that:

$$P(t)_{high} = P_0 e^{-0.0330(\alpha-\beta)t} \ (Equation\ 7.10)$$

$$P(t)_{low} = P_0 e^{-0.0124(\alpha-\beta)t} \ (Equation\ 7.11)$$

Where α is the probability of automation of tasks in a specific occupation and β is the overall relevance of the occupation in 4IR. The α values are derived from Figure 7-1 where mean values of the candlestick chart were taken as values thereof (see Table 7-5). The values of β were derived based on the work of the World Economic Forum (2016), the World Economic Forum (2018) and PwC (2018). According to these authors, occupations with high relevance to 4IR technologies have high levels of cognitive ability and social interaction with few routine tasks. These qualities were rated as per Table 7-6 for the purpose of this thesis and were used to derive β values in Table 7-7. The job qualities in Table 7-6 were given equal weight and the β is the mean thereof.

In this respect, Equations 7.10 and 7.11 can be incorporated into Equation 7.6 such that:

$$Y = \sum_{i=1}^{8} a_{ij} nP\{A \cap B\} e^{-0.0330(\alpha-\beta)t} \ (Equation\ 7.12)$$

$$Y = \sum_{i=1}^{8} a_{ij} nP\{A \cap B\} e^{-0.0124(\alpha-\beta)t} \ (Equation\ 7.13)$$

Where Equation 7.12 models the high rate of automation of tasks and Equation 7.13 models the low rate of automation of tasks. It should be noted that Figure 7.1 is based on ISCO-08 with nine major groups of occupations and to align it to OFO-2017, Skilled agricultural and fishery workers was ignored.

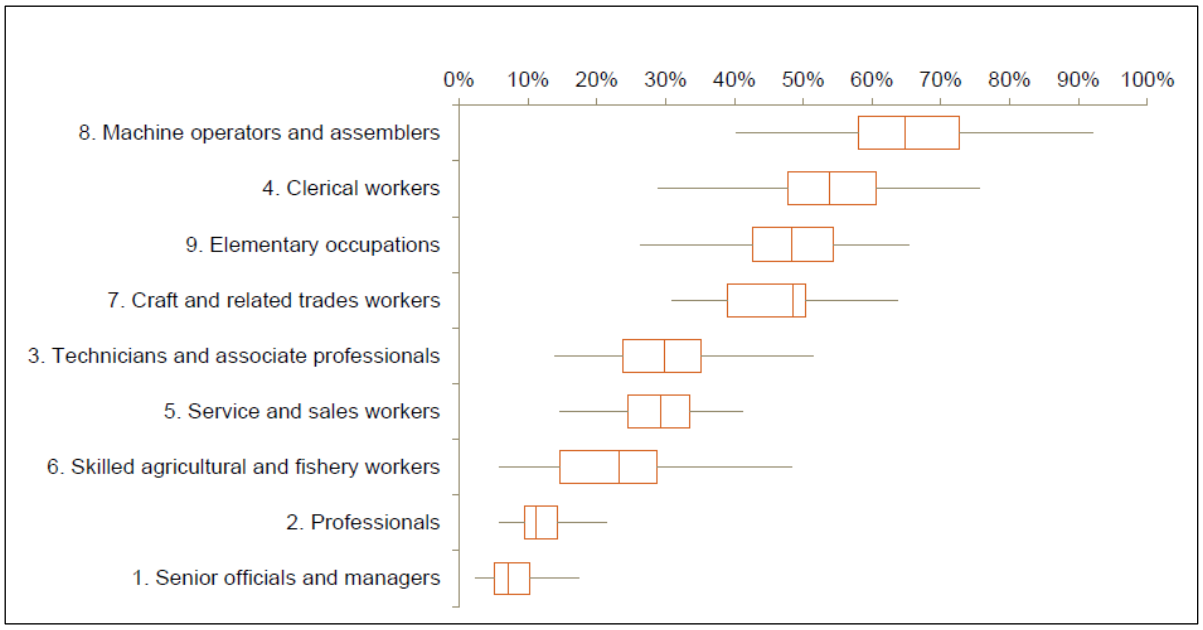


Figure 7-1: Potential risk of automation of tasks by occupation (PwC, 2018).

Table 7-5: The α value per major group of occupations.

Major Groups of Occupations	Probability of Automation (α)
1	8%
2	11%
3	29%
4	54%
5	27.5%
6	48%
7	65%
8	48%

Table 7-6: The ratings given to job qualities**.**

Rating	Cognitive ability	Social Interaction	Routine Tasks
1	High	High	Low
0.5	Medium	Medium	Medium
0	Low	Low	High

Table 7-7: The β value per major group of occupations.

Major Groups of Occupations	Cognitive ability Rating	Social Interaction Rating	Routine Tasks Rating	Relevance to 4IR Technologies (β)
1	1	1	1	1.00
2	1	1	1	1.00
3	1	0.5	0.5	0.67
4	0.5	1	0	0.50
5	0.5	0.5	0.5	0.50
6	0.5	0	0	0.17
7	0	0	0	0.00
8	0	0	0	0.00

Table 7-8 compares the results of the Equations 7.4, 7.6, 7.12 and 7.13. It should be noted that Equations 7.6, 7.12 and 7.13 are stochastic and in addition Equations 7.12 and 7.13 are time dependent. When comparing mean values in Table 7-8, when $n = 1$ and $t = 2021$ it can be observed that deterministic equation (Equation 7.4) gives optimistic result compared to stochastic equations, with time-dependent equation under high rate of automation of tasks (Equation 7.12) giving the most pessimistic result. Further it can be observed that the median and mode values in Equations 7.6, 7.12 and 7.13 are lower than their respective mean values, implying there is a high likelihood that employment opportunities will be less than the stated mean values.

Table 7-8: Comparison of the results of various equations of the employment estimator formula.

Models	Equation 7.4	Equation 7.6	Equation 7.12	Equation 7.13
Mean	315	295	239	270
Minimum		24	24	25
Maximum		945	798	856
Standard deviation		229	190	212
Median		211.5	167	194
Mode		162	54	40
Skewness		1.22	1.31	1.19
Iterations	1	1000	1000	1000

7.6. Validation of the employment estimator formula

To validate Equations 7.4, 7.6, 7.12 and 7.13, the 2021 employment data was obtained from one of the mines in the North West province. The mine has enlisted the services of nine contract mining companies and one engineering services company as shown in Table 7-9. In this respect, $n = 9$ for contract mining companies and $n = 1$ for engineering services companies in Equations 7.4, 7.6, 7.12 and 7.13 and $t = 2021$ in Equations 7.12 and 7.13. The results of the validation are shown in Table 9-10 with Figure 7-2 being the graphical presentation thereof in respect to the eight major groups of occupations. It can be observed in Figure 7-2 that there is a good comparison between the estimation results and mine data with correlation coefficients between mine data and Equations 7.4, 7.6, 7.12 and 7.13 being 0.938, 0.940, 0.943 and 0.942, respectively. According to Schober, et.al. (2018), a correlation coefficient of between 0.9 and 1.0 is considered as a very strong correlation.

Table 7-9: Employment data from a mine in the North West Province.

Company Type	Major Groups of Occupations								Sum*
	1	2	3	4	5	6	7	8	
Mining Contractors	12	33	103	5	0	74	349	744	1320
Engineering Services	1	0	40	0	0	20	16	0	77
Total	**13**	**33**	**143**	**5**	**0**	**94**	**365**	**744**	**1397**

Table 7-10: The results of employment estimator formulae.[27]

Equations	Company Type	Mean Values Major Groups of Occupations								Sum*
		1	2	3	4	5	6	7	8	
7.4	Mining Contractors	53	48	305	90	21	138	879	956	2490
	Engineering Services	4	2	5	3	0	11	4	8	38
Total		**57**	**50**	**310**	**93**	**22**	**149**	**883**	**964**	**2528**
7.6	Mining Contractors	31	28	180	53	13	81	518	563	1467
	Engineering Services	6	4	9	5	1	19	6	14	64
Total		**37**	**32**	**189**	**58**	**13**	**100**	**524**	**577**	**1531**
7.12	Mining Contractors	36	33	191	53	13	77	465	520	1388
	Engineering Services	7	5	10	5	1	18	6	13	64
Total		**45**	**38**	**201**	**58**	**14**	**95**	**471**	**533**	**1452**
7.13	Mining Contractors	33	30	184	53	13	80	497	547	1436
	Engineering Services	7	4	9	5	1	19	6	13	64
Total		**41**	**35**	**194**	**59**	**14**	**99**	**503**	**560**	**1500**

[27] It should be noted that the snap-shot of simulation results in Table 7-10 and Table 7-11 were taken at different times, hench the difference in the results.

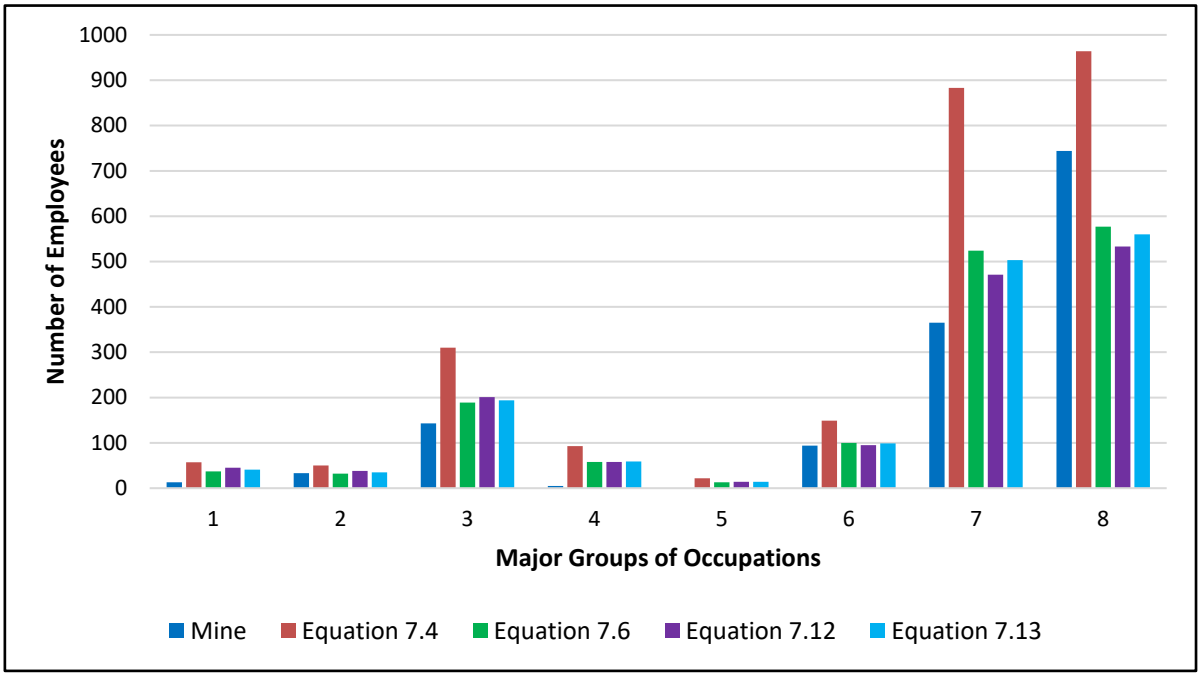


Figure 7-2: Comparison of mine data and the estimation of induced employment by the four employment estimator formulae.

7.6.1. Discussion

Table 7-9 displays the total number of nine mining contractors and one engineering services company at a mine in the North West Province where the total number in these company types is 1397. However, the number of employees estimated by Equations 7.4, 7.6, 7.12 and 7.13 as shown by mean values in Table 7-10 are higher than 1397, with Equation 7.4 giving the most optimistic estimation.

It can be noticed in Table 7-11, that Equations 7.6, 7.12 and 7.13, after 1000 iterations, resulted in outputs that are positively skewed, with the modes and medians being below their respective means. This points to the fact that there are few estimations with large values in the data sets, resulting in high mean values. To this effect, the probability of the total number of employees being below the mean value

in the case of Equations 7.6, 7.12 and 7.13 is 70.5%, 69.2% and 68.2% in the data sets, respectively. The total number of 1397 employees is within the probability ranges of these equations and it can therefore be stated that Equations 7.6, 7.12 and 7.13 can estimate employment opportunities of mining contractors and mining engineering services companies that may arise due to the demand for mining related services on a mine. Equation 7.4 is considered as less effective in estimating future state for planning purposes.

Table 7-11: Total number of employees provided by a mine for validation versus the estimation of the four equations derived for the employment estimator formula.

Models	Mine	Equation 7.4	Equation 7.6	Equation 7.12	Equation 7.13
Mine data	1397				
Mean		2528	2186	2166	2232
Minimum			144	104	136
Maximum			7613	7167	7422
Standard deviation			1969	1930	1962
Median			1447	1428	1470
Mode			247	590	816
Skewness			1.26	1.19	1.21
Iterations	1	1	1000	1000	1000

Equations 7.12 and 7.13 can also provide an opportunity to model growth or decline in employment opportunities over time. This is demonstrated in Figures 7-3 and 7-4 where it can be seen that employment in Major Groups 1, 2, 3 and 5 is likely to grow over time from index base of 100 in 2016, with Major Groups 1 and 2 having a pronounced growth. The growth in these four major groups of occupations is due to expected low probability of automation of tasks and relatively higher levels of relevance to 4IR technologies (β values of 0.5 and above).

On the other hand, employment in Major Groups 4, 6, 7 and 8 is likely to decline over time due to high probability of automation of tasks and relatively lower levels of relevance to 4IR technologies (β values below 0.5). In this case, the impact on employment in Major Group 4 (clerks) will be lower than in other major groups of occupations while employment in Major Group 7 (operators) is likely to be impacted severely. In mechanised mining, production output largely depends on the performance of operators and generally their tasks are repetitive. Therefore, it is not surprising that 4IR technologies generally target tasks under Major Group 7 in efforts to optimise output.

If we consider Major Groups 1 and 8 in both Figures 7-3 and 7-4, it is estimated that after 20 years from 2016, employment in Major Group 1 would have risen by 24.6% and 83.6% in environments of low and high rates of automation of tasks respectively. Conversely, employment in Major 8 would have declined by 14.9% and 34.9% in environments of low and high rates of automation of tasks respectively. This points to overall relatively high rates of increase in task with high relevance to 4IR technologies and relatively low redundancy rates in task with low relevance to 4IR technologies.

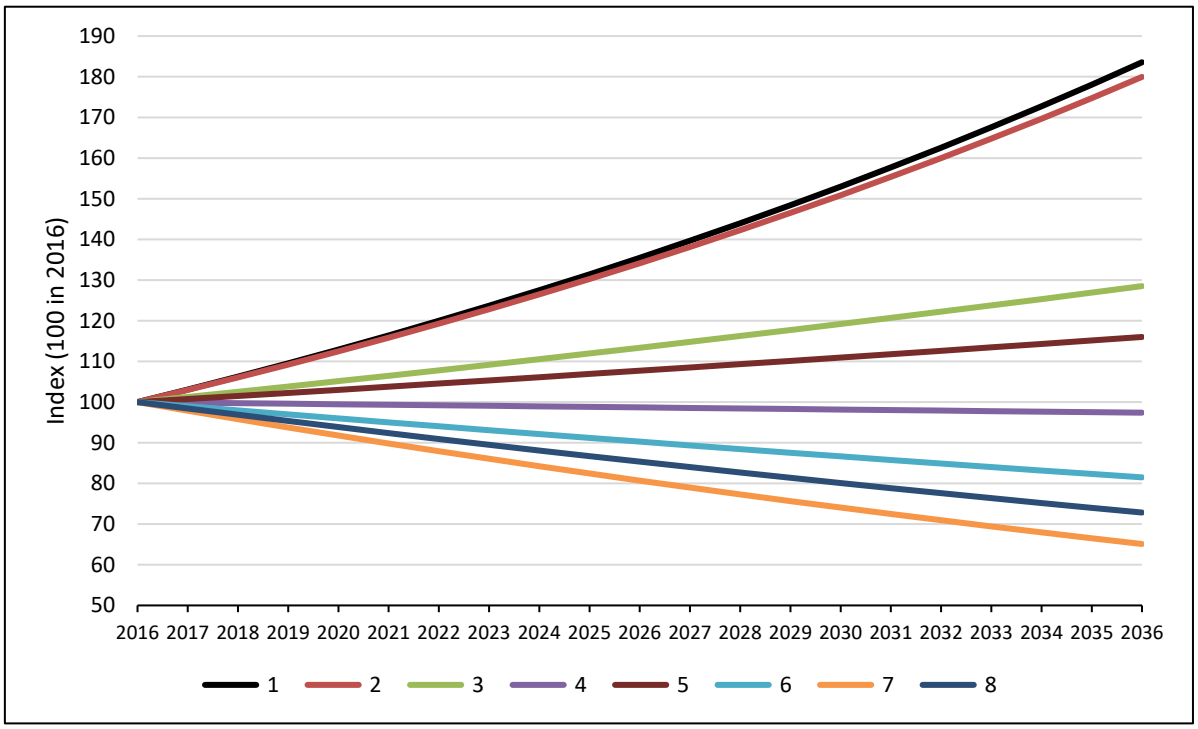


Figure 7-3: Modelled growth/decline of major groups of occupations when the rate of automation of tasks is high.

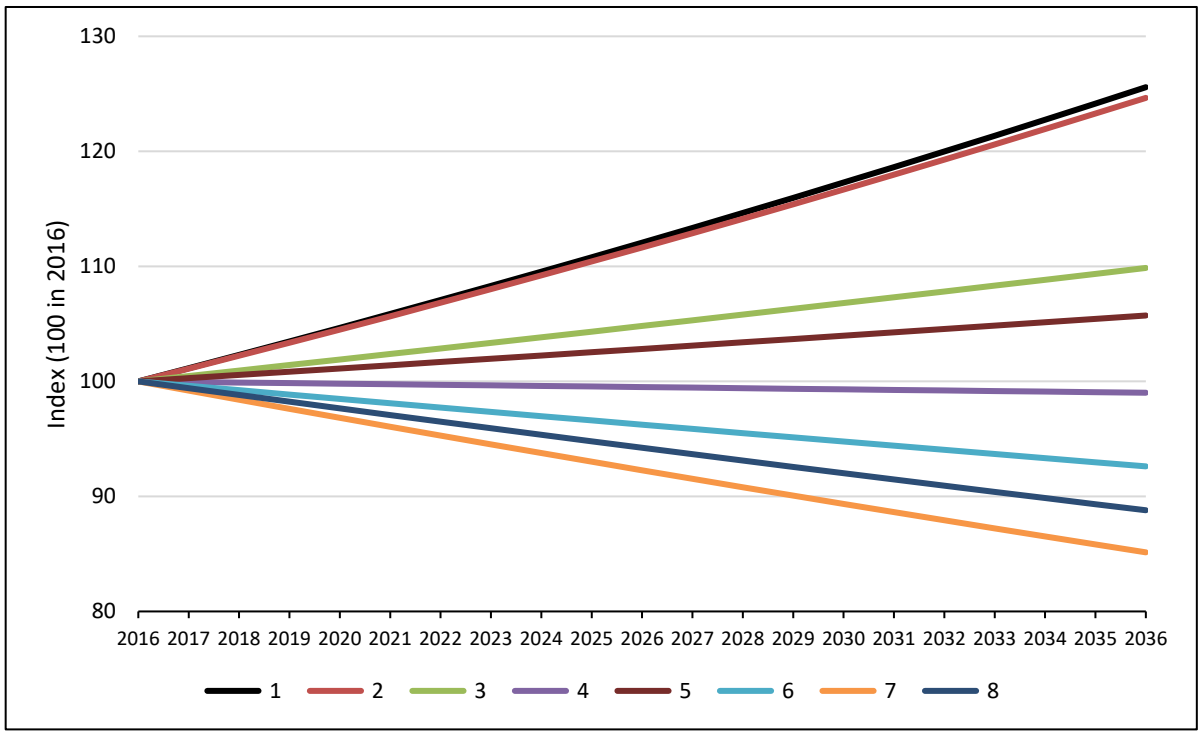


Figure 7-4: Modelled growth/decline of major groups of occupations when the rate of automation of tasks is low.

7.7. Summary

The purpose of this chapter was to derive employment estimator formulae. Given that mining contractors and engineering services companies work directly on mine site while other company types in most cases work off site, they were the only two company types considered when deriving employment estimator formulae. To this effect, one deterministic equation and three stochastic equations were derived. Two of the three stochastic equations, namely Equations 7.12 and 7.13, are time-dependent with the former estimating change in employment composition when the rate of automation of task is high and the latter estimating change in employment composition when the rate of automation of task is low.

When validating these equations, it was established that the results thereof have a strong correlation with validation data supplied by a mine in the North West Province. While the correlation of the mine data and the estimation of Equation 7.4 (deterministic equation) was strong, it is however over-estimating the number of employment opportunities induced. For example, the total number of mining contractors and engineering service company given by the mine is 1397 against the estimation of 2528 by the deterministic equation. Even then, 1397 was below the mean values of the estimation of the stochastic equations. However, given that after 1000 iterations, the results of the stochastic equations were positively skewed with 68.2% to 70.5% of the results being below the mean values ranging from 2166 to 2232, they provide realistic estimation. Furthermore, Equations 7.12 and 7.13 can be used to model growth or decline in major groups of occupations over time.

8. Conclusions and recommendations

8.1. Conclusions

The primary objective of this research was to develop an employment estimator formula to estimate employment in upstream industries to the mining industry in South Africa, specifically in the mining production backward linkage envelope, as the results of demand for goods and services. The secondary objective was to create an understanding of where jobs in the mining production backward linkage envelope are being created in South Africa due to mining production inputs.

To achieve these objectives, it was necessary to define technology in general and specifically mining technology, both which were defined under Definitions on page xvii. These definitions helped in the demarcation of the scope of this thesis along the mine value chain which in this case are activities bounded by the various fields of mining engineering, namely rock-breaking, rock engineering, mine ventilation, mine transportation (handling of personnel, material, broken rock and pumping) and support services such as mine planning, engineering geology, mine survey and equipment maintenance. Tasks within these fields are in themselves inputs into mining production (development, production of ores and removal of waste).

Technologies used in supporting fields such as exploration geology, other engineering disciplines, human resources, procurement, finance and downstream fields that include metallurgy and marketing were ignored. This narrow scope was necessary because a mine, from mine value chain perspective (exploration, mining,

processing and marketing), have a broad definition with some activities being outside mining production.

The definition of technology, led to typification and classification of mining input technologies into 12 technology nodes. In this respect, the four types of technology were identified as Artefacts & Chemical Technology, Machine Technology, Hardware & Software Technology and Mining Related Services Technology. Each of these technology types were divided into three classes according to the level of sophistication, with Class 3 being considered as the most complex per technology type, followed by Class 2 and Class 1 in that order.

To understand how economic linkages can create an environment that leads to creation of mining technology (using goods and services as the proxy thereof), it was necessary to revisit the resource linkage theory, particularly its origin from the balance and unbalanced growth doctrines. It was shown in Chapter 2 that there are five types of resource linkages, namely production, consumption, fiscal, spatial and lateral migration. The linkage of interest in so far as this thesis is concerned, namely backward linkage, falls under production linkage. Other linkage types under production linkage are forward and side-stream linkages and these two falls outside the scope of this thesis.

To understand manifestation of mining backward linkages internationally, case studies of four countries, namely Chile, Sweden, Australia and Ghana were undertaken. These countries were chosen because of two main reasons. Firstly, they have a long history of mining. Secondly, they are geographically dispersed around the globe (South America, Europe, Australasia and Africa, respectively). The case

studies revealed that Sweden and Australia have better mining backward linkages compared to Chile and Ghana. Sweden and Australia are exporters of home-grown mining technologies. Chile is beginning to emerge as an exporter of mining technology, particularly in the Latin Americas. By 2013 there were over 4 000 mining service providers in Chile, albeit majority of them being small in size. Ghana is a net importer of mining technology (over 80% of mining input technology is imported), although there is a drive since 2014 through the Minerals and Mining (General) Regulations L.I. 2173 to support local manufacturing companies and service providers.

South Africa is a developing country, but its mining backward linkages are comparable to those of Sweden and Australia (developed countries). The South African mining backward linkages can be described as important and strong. It was shown in Chapter 6 on the basis of technology incidents that the presence of South African companies in 11 of the 12 technology nodes was either dominant or significant. However, dominance in technology incidents does not refer to market share or procurement value, but merely a capability. Notwithstanding the preceding views, it was shown in Chapter 4 that the value of services into the South African mining industry was greater than that of goods, in line with the notion that the South African economy is skewed towards services.

To achieve the objectives of this thesis, data was collected from the Mining Qualifications Authority, LinkedIn, mining magazines and internet. The data collected with respect to 123 companies which employed 33 740 employees in total, pertained to the number of employees per major groups of occupations, physical locations of

these companies in South Africa, countries of origin of these companies, as well as goods and services provided.

The 123 companies in the sample were arranged into 13 company types, but overlapping in terms of goods and/or services provided. In the sample, there were more mining contractors (26 companies) than any other company type, followed by distributors (18 companies), training services providers (17 companies), and manufacturing companies and consulting services providers (13 companies each). The three company types with the highest number of employees in the sample of 123 companies were mining contractors (19 646 employees), manufacturing companies (3620 employees) and distributors (3263 employees).

When the number of employees per occupation group was analysed, it was established that 30% of employees in the sample were general workers (Group 8), followed by operators (Group 7) who accounted for 27% of employees in the sample. Operators were followed by technicians (Group 3) who accounted for 12% of employees in the sample. Group 5 which consists of occupations such as security guards and sales people accounted for only 2% of employees in the sample. The North West Province had the highest number of employees in the sample with 44.4% of the total.

The Gauteng Province was found to be a host to the highest number of companies in the sample, 78 out of the 123 companies located their head offices in the province. If metropolitan areas of the Gauteng Province were taken into consideration, then 28 head offices were located in the City of Johannesburg Metropolitan Municipality (Johannesburg, Sandton and Midrand), 27 head offices were located in the City of

Ekurhuleni Metropolitan Municipality (Germiston, Kempton Park, Boksburg, Springs, Bedford, Modderfontein and Lethabo) and 12 head offices were located in the City of Tshwane Metropolitan Municipality (Pretoria and Centurion). The Gauteng Province has also more manufacturing facilities than any other province. The implication was that the province had a high number of employees in Major Groups 1, 2, 3, and 6. Incidentally these are occupation groups that are likely to see significant appreciation in employment opportunities under Mining 4.0 technologies. In this respect, Research Question 1 was addressed.

When data was analysed, it was found that only mining contractor and engineering services company types had employees that were working on long-term basis on the mine, in others it was inconclusive with respect to duration of employees, if any, on the mine and their numbers. It was then decided to exclude all other companies and focus on mining contractors and engineering services companies in the derivation of employment estimator formulae. This decision was supported by data provided by a mine in the North West Province that was used to validate employment estimator formulae.

To this effect, one deterministic equation (Equation 7.4) and three stochastic equations (Equations 7.6, 7.12 and 7.13) were derived. Two of the stochastic equations were time-dependent, i.e., Equation 7.12 modelled the growth or decline of number of employees in each major group of occupations over time under conditions where there was a high rate of automation of tasks in general. Equation 7.13, on the other hand, modelled the growth or decline of number of employees in

each major group of occupations over time under conditions where there was a low rate of automation of tasks in general.

When these equations were validated, it was established that they all have strong correlation with the data provided by the mine mentioned above. However, it was also established that Equation 7.4 will have the tendency to over-estimate the number of employment opportunities that may be induced if a new mine is established, for example. Stochastic equations produced results that were positively skewed with approximately 70% of the results being below the mean. The data from the mine used for validation also fell within the 70% data range, which led to a conclusion that stochastic equations are suitable to estimate the number of induced employment opportunities in the mining production backward linkage envelope, only with respect to mining contractors and engineering services companies.

Furthermore, Equations 7.12 and 7.13 can be used to model growth or decline in major groups of occupations over time. The models based on these equations predicted employment growth in Major Groups 1, 2, 3 and 5 over time in both environments of high and low automation of tasks while decline was predicted in Major Groups 4, 5, 7 and 8. It is likely that the rate of employment in Major Groups 1, 2, 3 and 5 will be higher than the rate of employment redundancy in Major Groups 4, 5, 7 and 8, with employment in Major Group 7 being the most at risk. In this respect, Research Questions 2 and 3 were addressed affirmatively.

Employees under Major Groups 4, 5, 7 and 8 tend to be sourced locally where mines are located and employees under Major Groups 1, 2, 3, and 6 (in so far as sales people are concerned) are generally located in the Gauteng Province due to

clustering of companies in the mining production backward linkage envelope. It can be said that Mining 4.0, over time, is most likely to favour the creation of employment opportunities in the Gauteng Province to the detriment of other provinces unless there is a policy intervention in South Africa.

It is envisaged that mining companies, mining contractors, engineering services companies, policy makers and the MQA will use the employment estimator formulae for employment forecasting and modelling as result of mining activity, especially in rural areas. Proper planning in this regard, not only in terms of total numbers, but also number per major groups of occupations, can enhance and clarify terms of social license to mine.

8.2. Contribution to knowledge

a. With respect to the primary objective of this thesis, Equations 7.4, 7.6, 7.12, and 7.13 were derived. However, this equations are only applicable to activities related to mining contractors and engineering services companies on the mines.

   While the intention was to derive the employment estimator formula for the entire mining production backward linkage envelope, ultimately the derived formulae are only applicable to Class 1 and Class 2 of Mining Related Service type. A rethinking is required on how to derive an employment estimator formula for non-mine based work like consulting and manufacturing.

Notwithstanding the above, the derived formulae in this thesis are significant in the sense that:

- Employees in Class 1 and Class 2 of Mining Related Service type constituted 60% of employees in the sample.

- The bulk of employees employed by mining contractors and mining services companies come from mining host communities. Most of these communities are impoverished and generally there is a high expectation that they will find employment on the mine. In this case, mining contractors and mining services companies are potential alternative employers.

- Mining, as observed by Davis and Tilton (2002), in rural areas crowds out productive sectors such as agriculture and small-scale manufacturing (craft work) due to expectation of regular salary paid by mines, mining contractors and mining services companies. It is therefore important to accurately estimate and forecast employment that may be created by the establishment of a mine in a community (especially rural and impoverished communities) to avert unrealistic expectations of employment.

b. With respect to the secondary objective of this thesis, it was found that:

- Employment opportunities related to contract mining and engineering services are created in mining provinces such as Free State, Limpopo, Mpumalanga, Northern Cape and North West. These company types tend to hire proportionally higher numbers of Groups 7 and 8 employees (see Figures 6-12, 6-15, 6-16, 6-17 and 6-18) compared to companies in non-

mining provinces such as Eastern Cape, Gauteng and Western Cape (see Figures 6-11, 6-13 and 6-19).

In this respect, one of the eminent threads is Mining 4.0 technologies which may result in massive redundancy in Group 7 and 8 occupations. However, there is a possibility that this redundancy will be minimised in South Africa mainly due to:

- High levels of unemployment (32.6% in the first quarter of 2021). In this regard, there could be social and political pressure for companies to use labour intensive technologies and delay or refrain from using technologies that will automate tasks at a high rate in the mining industry. The assumption in this case is that mines through their supply tenders will have a bearing on the intensity of technology expected to be used by their contract mining and engineering services suppliers;

- There is high likelihood that mine modernisation technologies in the narrow reef mining will be low technologies compared to autonomous haulage systems used in surface mining in Australia for example (Mining Technology, 2021). Low levels of technology will limit the extend of redundancy in Group 7 and 8 occupations that may result due to Mining 4.0 technologies like autonomous haulage systems and automine.

- This research agrees with the work of Lydall (2009) and Kaplan (2011) in that there are a more companies in the Gauteng Province than any other province in South Africa that supply the mining industry with goods

and services, even though the focus of this thesis was on mining production backward linkage envelope. In this instance, despite the concentration of company types such as OEMs, manufacturing companies, consulting companies and distributors being in the Gauteng Province, most of employees (in the sample) are in the North West Province, majority of whom are employed by mining contractors.

8.3. Recommendations and suggestions for further research work

While the work done in deriving equations pertaining to the employment estimator formula holds based on the results of the validation, further validations with respect to underground massive mining, underground coal mining and surface mining must be done. Furthermore, more work must be done to derive employment estimator formulae with respect to input goods and non-mine based work in the mining production backward linkage envelope.

Given that the focus of this research was on mining production backward linkage envelope, there is a scope to use methodology followed in this thesis to derive employment estimator formulae that will be applicable at every node along the mineral value chain. This will provide an added dimension of employment inducement factors in value chains conceived in the South African Beneficiation Strategy (see Table 1-3).

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Appendix A

Table A1: Concentration of activities and distribution of labour for mining contractors.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Mining Contractor A										7110	0990	7110	9	15	103	13	0	58	193	232
Mining Contractor K											0990		20	13	7	11	0	1	3	7
Mining Contractor B											0990		5	9	7	21	6	21	37	19
Mining Contractor C											0990; 0990	7110	38	65	228	110	40	150	1030	1256
Mining Contractor D											0990		38	27	69	56	1	41	248	171
Mining Contractor E											0990		3	0	13	3	0	5	21	17
Mining Contractor F											0990		4	2	1	0	0	0	3	4
Mining Contractor G											0990		5	8	96	11	2	22	296	121
Mining Contractor H											0990		5	0	22	7	0	0	34	123
Mining Contractor I										3312	0990		23	10	34	15	8	34	62	74
Mining Contractor J										3312	0990		7	0	18	8	0	0	5	3
Mining Contractor L											0990		5	2	32	10	0	2	92	70
Mining Contractor M											0990		30	9	162	56	3	0	121	1487
Mining Contractor N											0990		3	9	22	13	0	4	125	173
Mining Contractor O										3312	0990		32	52	474	184	34	561	1448	1286
Mining Contractor P											0990		9	6	123	11	1	78	150	151
Mining Contractor Q											0990		27	9	176	35	0	47	989	450
Mining Contractor R											0990		41	21	337	58	89	45	1775	1408
Mining Contractor S											0990		10	6	107	11	4	9	211	350
Mining Contractor T											0990		3	2	71	7	2	10	194	284
Mining Contractor U											0990		4	2	8	6	0	35	15	21
Mining Contractor V											0990		2	1	6	1	0	1	2	5
Mining Contractor W											0990		2	4	7	5	2	9	38	37
Mining Contractor X											0990		4	3	6	3	0	5	14	19

Mining Contractor Y											0990		3	1	4	2	0	5	12	5
Mining Contractor Z												7110	3	13	1	5	0	0	0	0

Table A2: Concentration of activities and distribution of labour for manufacturing companies.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Manufacturer A			2011								0990		34	41	132	49	0	62	293	174
Manufacturer B			2720							3312			10	15	11	10	3	36	9	15
Manufacturer C			2029				2630		6201	6202			36	36	54	37	1	20	110	158
Manufacturer D			2029				3290		3290			7110	23	53	86	79	3	39	170	248
Manufacturer E		2811											11	19	8	6	3	16	5	25
Manufacturer F	2220; 1520; 1399												8	5	7	8	3	9	24	24
Manufacturer G			2011							0990	0990		17	6	90	4	0	7	305	127
Manufacturer H	4763	2811								7490			5	1	11	23	4	15	5	49
Manufacturer I		2811								3312			8	8	3	17	3	13	4	21
Manufacturer J			2029				4731		4731	6202			14	20	10	25	2	20	57	78
Manufacturer K	2599												3	2	5	6	0	49	3	12
Manufacturer L	2211												1	0	1	0	0	1	73	14
Manufacturer M			2029								0990		7	24	34	26	0	23	69	97

Table A3: Concentration of activities and distribution of labour for distributors.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Distributor - General A							4731						3	4	2	0	0	1	2	2
Distributor - General B	4763; 4763									3320; 3312			1	0	15	10	3	4	1	0
Distributor - Machine A					4742					3312			5	1	0	4	3	1	2	2
Distributor - Machine B	3290; 4763			4742; 3290	4742			4731		3312			109	141	82	155	37	246	99	303
Distributor - Machine C					4742					7730; 0990			2	0	2	0	0	9	88	0
Distributor - Machine D	2811; 4763	2811; 4763		2824	2824						0990		15	13	9	19	0	2	0	7
Distributor - Machine E	4763; 2811	4763; 2811		4742; 3290						3312			7	5	17	21	3	25	10	32
Distributor - Machine F	2811; 4763			4742	4742			4731		3312			75	48	29	36	4	16	13	26
Distributor - Machine G	2811; 4763	4763		4742; 3290	4742			4731		3312			17	7	19	25	9	11	9	18
Distributor - Software A							4731	4731		6202			6	26	8	7	0	0	0	0
Distributor - Software B								4731		8549; 6202			1	22	4	3	0	0	0	0
Distributor - Software C								4731	4731	6202; 8549		7110	6	23	2	3	0	0	0	0
Distributor - Software D								4731	4731	6202; 8549		7110	7	15	2	1	0	0	0	0
Distributor - Software E								4731	4731	6202; 8549		7110	6	13	7	1	0	0	0	0
Distributor - Software F								4731	4731	8549; 6202		7110	9	17	4	6	6	1	1	5
Distributor - Machine H	4763; 4763	4763		4742; 3290	4742					3312		7110	36	50	167	227	29	231	88	291
Distributor - Software G								4731	4731	8549; 6202			5	2	5	2	0	0	0	0
Distributor - Software H								4731		6202			10	6	0	3	0	0	0	3

Table A4: Concentration of activities and distribution of labour for OEMs.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
OEM A	3290; 4763	2811; 4763		2824; 4742; 3290	4742					3312			11	11	23	21	1	38	13	41
OEM B							4731; 2630	6201		3312			4	3	12	6	4	17	3	5
OEM C		2651; 4742								3313			15	29	10	4	0	1	0	1
OEM D							2630; 4731						5	15	18	18	6	40	6	11
OEM E	2599	2599		2824; 3290						3312			4	1	2	10	1	9	2	11
OEM F							2630						12	31	12	9	5	45	8	12
OEM G	2599	2599		2824; 2813						3312	0990		5	0	48	7	0	7	0	130
OEM G	2811				2813; 3290					3312			3	3	2	3	1	10	9	6
OEM H	2811			2813						3312; 3320; 8549			20	55	63	74	7	175	168	120
OEM I					3312								6	0	5	4	2	2	2	2
OEM J							2651; 2651	6201					11	22	36	8	3	41	8	11
OEM K			2720; 2011				3290; 2630						9	12	83	40	6	101	17	26

Table A5: Concentration of activities and distribution of labour for training service providers.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Training Services A										8549			3	31	0	5	0	0	0	2
Training Services B												8549	10	292	12	42	18	1	0	46
Training Services C												8549	2	60	3	18	7	0	0	8
Training Services D										8549			4	2	6	1	0	0	0	0
Training Services E											8549		4	15	3	4	0	0	0	1
Training Services F										8549; 3320			21	69	26	24	4	44	14	11
Training Services G										8549		8549	5	21	2	11	0	0	0	4
Training Services H											8549		9	51	0	0	0	15	0	4
Training Services I												8549	3	2	0	1	0	0	0	0
Training Services J										8549			3	0	0	0	0	9	0	1
Training Services K										8549			5	14	4	3	0	0	0	0
Training Services L												8549	3	30	0	6	0	0	0	4
Training Services M												8549	2	8	1	8	1	0	0	1
Training Services N												8549	4	26	1	2	0	0	0	0
Training Services O										8549		8549	5	32	0	2	1	0	0	0
Training Services P										8549; 0990			37	130	43	50	25	6	12	10
Training Services Q										8549			1	1	0	5	0	0	0	0

Table A6: Concentration of activities and distribution of labour for consulting companies.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Consulting A												7110	5	0	0	0	0	0	0	0
Consulting B												7110	5	15	2	4	0	0	0	1
Consulting C										7110; 8549			14	22	18	8	0	0	0	1
Consulting D										7110		7490	122	291	190	123	0	52	4	10
Consulting E										0990			9	10	9	15	6	2	3	0
Consulting F												7110	2	5	0	2	0	0	0	0
Consulting G											0510	7110	4	2	1	2	0	0	0	0
Consulting H												7110	6	8	1	4	0	0	0	0
Consulting I												7110	8	4	8	3	0	0	0	1
Consulting J												7110	21	227	19	44	0	0	1	1
Consulting K												7110	5	16	14	1	0	1	0	0
Consulting L												7110	5	23	0	8	0	1	0	1

Table A7: Concentration of activities and distribution of labour for industry organisations.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Industry Organisation A											0990		90	474	271	246	54	0	0	8
Industry Organisation B											7490		13	31	7	14	1	1	0	0
Industry Organisation C											7490		15	18	12	14	0	2	2	2

Table A8: Concentration of activities and distribution of labour for engineering service providers.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Engineering Service A										3312			9	2	1	7	0	7	3	5
Engineering Service B				4742						3312			8	3	4	12	0	14	1	6
Engineering Service C										3312			3	1	5	5	0	43	0	64
Engineering Service E		4763								7490			5	1	12	2	5	8	1	6
Engineering Service F										3312			5	6	9	3	0	79	18	8
Engineering Service G									4763	3312			5	1	1	0	0	2	0	1
Engineering Services H										3312			4	1	25	0	0	17	0	0
Engineering Services I										0990			18	0	0	1	0	3	115	18
Engineering Services J										7490			3	15	1	1	0	0	0	0
Engineering Services K		3290					4731			3312; 3320			3	1	10	3	0	9	1	5
Engineering Services L										3312			1	3	10	8	0	7	4	10

Table A9: Concentration of activities and distribution of labour for software developing companies.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Software Developer A								6201		8549		7110	2	5	0	3	0	0	0	1
Software Developer B								6201		6202; 8549			1	18	26	5	0	0	0	0
Software Developer C									6201				2	1	7	2	0	11	0	1
Software Developer D							2630						14	7	3	10	1	23	4	6

Table A10: Concentration of activities and distribution of labour for research laboratory.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Research Laboratory A											7490		7	2	31	15	0	0	77	1

Table A11: Concentration of activities and distribution of labour for education institutions.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Education Institution A										8549	8549		5	31	3	5	4	0	2	3
Education Institution B											8549	8549; 7490	2	20	3	4	0	0	3	1

Table A12: Concentration of activities and distribution of labour for fuel depots.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Fuel Depot A		4763											4	0	2	6	30	0	0	0
Fuel Depot B		4763											0	1	3	6	0	0	3	3

Table A13: Concentration of activities and distribution of labour for EPCM company.

Company	SIC Codes Assigned to Technology Nodes												Number of Employees per Major Groups of Occupations							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
EPCM A										7110			7	18	22	8	0	0	0	1