A Fuzzy Cognitive Mapping Approach to Scenario Development in the South African Mining Industry

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DECLARATION

I, C. Ackermann , declare that this consultancy report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the Graduate School of Business Administration, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Christiaan Ackermann

Signed at ……………………………………………………

On the …………………………….. day of ………………………… 2018

DEDICATION

To my lovely wife, Andrea, and our new born daughter, Adeleine - you have been my rock throughout the MBA and it has all been for you.

To my Lord who gives me strength and has blessed me with this opportunity – may I walk in the plan You have for me and use this newfound knowledge to glorify Your name.

To all the friends, family, colleagues, and classmates who have supported me in this incredible journey for the past two years – may we continue to build up each other, dream together, and share fulfilling lives that make a difference.

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SUPPLEMENTARY INFORMATION

Supervisor:	Eduan Pieterse
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Supplementary files:	Appendix A - Future Scenarios
	Appendix B - Recommendations
	Appendix C - Survey Results
	Appendix D - Data Analysis Model – Full Dataset
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† Including Executive Summary, References, etc.

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GLOSSARY

Acronym	**Meaning**
Amplats	Anglo American Platinum Limited
ANC	African National Congress
ANCYL	African National Congress Youth League
AAMSA	Association of Mine Managers South Africa
BEE	Black Economic Empowerment
COSATU	Congress of South African Trade Unions
CSR	Corporate Social Responsibility
DRC	Democratic Republic of Congo
EPCM	Engineering, Procurement, and Contract Management
FCM	Fuzzy Cognitive Map
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
IMF	International Monetary Fund
JSE	Johannesburg Stock Exchange
KDF	Key Driving Force
LOM	Life of Mine
MBA	Master of Business Administration
MPRDA	Mineral and Petroleum Resources Development Act of 2002
NDP	National Development Plan
NUM	National Union of Mineworkers
SME	Small to Medium Enterprise
TIA	Trend Impact Assessment
SA	South Africa
US$	United States of America Dollar
USA	United States of America
WEF	World Economic Forum
ZAR	South African Rand

EXECUTIVE SUMMARY

The South African mining industry is faced with real challenges that have been devastating in the past. Prolonged labour unrest, regulatory uncertainty, and the aftermath of a global recession which saw commodity prices plummet have impacted on the economy in long lasting ways. Due to these local and global influencers mining executives are now more than ever faced with a critical question: “What does the future of South African mining look like?”

Scenario planning, a subset of strategic foresight, is geared towards answering this question by defining the future through multiple lenses and developing robust strategies that cater for more than one version of the future. Mining executives typically develop future scenarios qualitatively, from expert views, but there is a need to develop data-driven scenarios due to the speed and depth of complexity that can be gained. Also, an understanding of what the main industry components and drivers are is required.

Therefore, this consulting project develops a systemic view of the South African mining industry, making use of a Fuzzy Cognitive Map, to provide mining executives with a data-driven scenario planning toolkit. The Fuzzy Cognitive Map defines nodes and interrelationships from existing research and is converted into a quantitative model, using an adjacency matrix. Data was collected from 73 South African mining executives to calibrate the model’s causal relationship weights between nodes, and therefore has a high level of credibility.

The most sensitive drivers are determined and two scenarios with expected outcomes are used to validate the model. Once validated, the model can now be used by mining executives to develop any other future scenarios within the South African mining industry.

Preparing for divergent futures ensures robust strategies are pursued, which provide a competitive advantage in a tough industry. The data-driven scenario planning methodology proposed in this project allows for the development of scenarios that are richer in complexity, quick to develop and analyse, and rooted in data, enhancing the strategic planning capability for South African mines.

Keywords: Fuzzy Cognitive Map, Adjacency Matrix, South African Mining Industry, Scenario Planning, Strategic Foresight, Semi-Quantitative, Causal Relationships

1. PROBLEM STATEMENT

The SA mining industry has experienced numerous unforeseen challenges since its inception in the late 1800's, such as market volatility, political instability, and regulatory uncertainty. Now more than ever before these challenges have become so intense that the industry is in survival mode (Neingo & Tholana, 2016).

In the past decade the mining industry weathered the global economic crunch since 2008 (Arieff, 2010) which caused commodity prices, i.e. gold, platinum, iron ore, copper, coal, etc. to reduce by 30% between 2008 and 2009, increase by 60% between 2009 and 2011, and fall again by 48% between 2011 and 2016 (International Monetary Fund, 2017). Also, labour unrest has regularly crippled the industry in the last 10 years, as seen by the Marikana wildcat strike and shooting in 2012 and the 5-month platinum strike in 2014 which decreased mining production by 6.5% year-on-year (Mining Review, 2014). Another outstanding challenge is illegal miners. Zama Zamas (the Zulu word for illegal miners (Council on Foreign Relations, 2016)) have stolen over R72 billion in gold revenue and R63 billion in platinum group metals (PGM) revenue in 2013 (The Citizen, 2015).

These are just a few of the challenges the industry is faced with. The fact is these challenges are real and cripples the industry. Recently, Anglo American Platinum (Amplats) and Impala Platinum (Implats) have indicated to reduce their labour force with 13 000 (Bloomberg, 2018).

Because of major capital investment and regulatory barriers to entry into the mining industry future planning and strategic positioning is key for long-term success in the midst of local and global industry influencers (Lane, Guzek, & Van Antwerpen, 2015).

Scenario planning has been used in conjunction with causal drivers to understand the global platinum mining industry, as described by (G. Smith, Surujhlal, & Manyuchi, 2008) and (G. L. Smith, 2012). Also, various scenarios have been developed for the overall SA economy, such as the Mont Fleur scenarios in 1992 to imagine Mandela's release and the end of Apartheid (Van Der Heijden, 2000), but limited other research was found during this project that describes the overall SA mining industry in a systems thinking approach. Scenario planning can play a key role in assisting SA mining companies to plan for the long-term future (Lane et al., 2015). SA mining companies would therefore benefit from a systems view of the industry which describes the KDFs and supports the scenario planning process as this can be tailored for each operation and provide a competitive advantage (Lane et al., 2015).

> **Main Problem:** SA mining companies may not have a systemic view of the industry that is agile and can be used for scenario planning. This may place the SA mining industry at a competitive disadvantage globally due to not effectively planning for the long-term future and ensuring the sustainability of mining operations. There is therefore a definite need for a systemic view of the SA mining industry that can be used to perform scenario planning.

Scenario planning has traditionally been an applied science that involves defining a system and its KDFs through qualitative data collection methods, such as interviews with industry experts (Van der Merwe, 2008). Academics have therefore criticised the discipline as not being data-driven, however it has been considered a useful applied practice by industry leaders, such as Royal Dutch Shell, making use of systems thinking theory (Van der Merwe, 2008).

> **Sub-Problem 1:** Scenario planning is mostly qualitative (i.e. subjective) and mining executives therefore often need to rely solely on the experience and subjectivity of experts. There is a definite need for mining executives to convert this expertise into a data model and develop data-driven scenarios to prepare for the future.

Traditionally, scenario planning in the mining industry is a long and complex process, e.g. the World Economic Forum engaged with 200 global leaders in mining over a one-year period to produce three future alternative scenarios for the global mining sector (World Economic Forum, 2009).

> **Sub-Problem 2:** The scenario planning process takes a long period of time and needs to be revised continually as industry foresight knowledge changes.

> This poses a risk for decision makers who need to make quicker decisions and align their strategies to future scenarios. There is a definite need to develop scenarios quicker to enhance strategies and decision making.

The SA mining industry is complex but when using traditional scenario planning techniques one is typically limited to describing future scenarios within two or three industry drivers, i.e. the axis method (Amer, Daim, & Jetter, 2013). The human mind also struggles to comprehend more complexity than comparing two things at a time, or multitasking (Rogers & Monsell, 1995), hence traditional scenario planning approaches may lack the depth of complexity when defining future scenarios

> **Sub-Problem 3:** Traditional scenario planning approaches may describe scenarios with limited depth of complexity which erodes the richness of the scenario and its potential value. There is therefore a definite need to develop scenarios with greater depths of complexity.

This research project proposes a solution to the Main Problem and its three Sub-Problems by developing a theoretical systemic model of the SA mining industry from research. The theoretical model is converted to a FCM and used for scenario planning in a semi-quantitative approach. This assists SA mining companies to formulate data-driven future scenarios at a much faster rate and with more depth of complexity, to make informed decisions and gain a competitive advantage.

2. LITERATURE REVIEW

2.1. The South African Mining Industry's Key Driving Forces

2.1.1. Section Introduction

The purpose of this section is to provide an overview of the SA mining industry and identify the KDFs that may be prevalent in the industry. These KDFs are used in section 3.3 as the nodes of the FCM. Also, the FCM's causal relationships defined in section 3.4 are substantiated in this section by inferring from research how each KDF may influence other KDFs. This section highlights 12 KDFs and 35 causal relationships between these KDFs, from the research provided.

2.1.2. South African Mining Industry Overview

The SA economy was predominantly built on the mining industry, with major diamond and gold discoveries in the late 1800's. Today, SA is the world's largest producer of chrome, manganese, platinum, vanadium, and vermiculite, the second largest producer of ilmenite, palladium, rutile, and zirconium and the third largest producer of coal. Iron ore exports to China, the world's largest iron ore consumer, also ranked third in the world in 2013 (Chamber of Mines, 2016). With more than 52 commodities underground, SA's resources have an estimated value of US$2.5 trillion (Lane et al., 2015). In 2016, the SA mining industry enabled R120bn in employee earnings, contributed R304.4bn to Gross Domestic Product (GDP) (i.e. 7.3%), supported 4.5 million dependants, created 457,698 direct jobs, and exported 88% of all metals. The industry is also a major contributor to the fiscus through taxes and royalties and other sectors, i.e. in 2016 R211.8bn was spent on goods and services (World Economic Forum, 2009).

Although having reached tremendous peaks during the 20th and 21st centuries to date, the SA mining industry has also experienced major difficulties, such as commodity price fluctuations, political instability, increased regulatory requirements, global competition, barriers to technology innovation due to high unemployment levels, and slow economic growth (Lane et al., 2015).

SA mining companies are highly exposed to global factors, such as macro-economic growth and international markets, which determine the demand and price for mining commodities (Lane et al., 2015). USA, Europe, and China are still slowly recovering from the 2008 global recession, with Europe having faced a sovereign debt crisis and Brexit structural reforms (Lane et al., 2015), and the USA is showing signs of protectionist regimes under the Trump administration. The world has therefore looked to Asia to drive demand (Lane et al., 2015), but China, as the main historical customer, adopted an export strategy which saw iron ore prices fall in 2015 (Chamber of Mines, 2016).

2.1.3. Summary of Key Driving Forces

Mining operations in SA operate within an ecosystem that comprises various social, environmental, economic, regulatory, and political factors. The ecosystem may be viewed as a closed system with boundaries for the purposes of this study and only includes major concepts that will significantly influence the operations of a mining operation in SA.

The SA mining industry is influenced by external and internal KDF, which (Lane et al., 2015) describes as the global and local influences on SA mining operations. External KDFs influence the system from outside and can't be influenced by the system itself, whereas internal KDFs can influence and be influenced.

(Lane et al., 2015) identifies five external KDFs which are used in section 3.3 as the FCM Transmitter Nodes (i.e. external inputs to the FCM) and are as follows:

1. Resource nationalism (section 2.1.4)
2. Market commodity prices (section 2.1.5)
3. Industrialisation and urbanisation (section 2.1.6)
4. Global economic recovery (section 2.1.7)
5. Africa attractiveness (section 2.1.8)

(Lane et al., 2015) further describes the four local (i.e. internal) KDFs on SA mining operations and these are used in section 3.3 to define the response nodes of the FCM. The internal input KDFs are as follows:

6. Regulatory environment uncertainty (section 2.1.9)
7. Government demands (section 2.1.10)
8. Labour unrest (section 2.1.11)
9. Pressure on margins (section 2.1.12)

Lastly, the mining industry also produces outputs back into the ecosystem which contribute to the SA economy, as described by (Antin, 2013). These three KDFs are classified as internal KDFs and used in section 3.3 to define response nodes of the FCM. The internal output KDFs are as follows:

10. Export revenue (section 2.1.13)
11. Foreign direct investment (section 2.1.14)
12. GDP growth (section 2.1.15)

For the purposes of complying to the requirements of the MBA consultancy report, with limited available time and resources, the combined research of (Lane et al., 2015) and (Antin, 2013) was used to define all the KDFs in the scope of the SA mining industry. It is acknowledged that other KDFs may exist within the SA mining system boundaries and other researchers may construct the nodes and causal relationships differently than in this study, however it is the intention of this project to validate the nodes and causal relationships through a survey questionnaire (see section 4). Also, the rationale for not including all potential causal relationships between each concept (i.e. each concept being related to each other concept) is for simplification of the FCM model as only the major causal relationships are included and inferred from research.

Therefore, 12 concepts are defined from the research to make up the SA mining industry's ecosystem. The following sections will describe each of the 12 concepts and identify the basis of each of the 35 causal relationships between concepts, as is defined in section 3.4.

2.1.4. Resource Nationalism

Resource nationalism is a public sentiment of state-owned resources with its roots stemming from the Freedom Charter of 1955, the Mineral and Petroleum Resources Development Act (MPRDA) of 2002 and the Mining Charter of 2004. The socio-economic trend of resource nationalism is evident in SA and globally as governments want a higher portion of the profits made from mining resources in their countries (Lane et al., 2015).

(a) State interventions, such as imposed resource-based taxes, create uncertainty for investors and further challenge the profitability and operability of mining operations. (Basis for causal relationship 1) in section 3.4.1)

(b) Although the SA government has no short terms plans to nationalise mines, these intentions were first debated and publicised by proponents and has subsequently significantly reduced the confidence and investment in the industry, which costed the SA economy billions in development finance (Lane et al., 2015). (Basis for causal relationship 2), 5), and 6) in section 3.4.1)

(c) Seen as a vehicle for increasing state revenues through mineral rights sales, taxation, and royalties, and fighting the legacy of apartheid with BEE employment and ownership, resource nationalism was debated heavily in 2010, but was ultimately not pursued (Antin, 2013). (Basis for causal relationship 3) in section 3.4.1)

The benefits of resource nationalism are public sentiment, not proven with evidence, and when commodity prices were booming people criticised government, lobbying for mines to be nationalised. Also, nationalisation of mines unlocks opportunity for unions, such as COSATU, NUM, and ANCYL to gain more political power (Antin, 2013). Julius Malema, as part of the ANCYL, challenged the president, Jacob Zuma, and the ANC over nationalisation and was seen by many as a voice of the people, however this caused a divide in the state party and political instability, to the point of a downgrade of the Rand by credit ratings agency Moody's (Antin, 2013).

(d) (Lane et al., 2015) states that the trend of global resource nationalism has caused uncertainty in the regulatory and policy making environment. (Basis for causal relationship 4) in section 3.4.1)

2.1.5. Market Commodity Prices

Mining is a commoditised industry with inelastic demand, hence a low market sensitivity to market prices. This is mainly due to mining being a primary industry that is essential for human existence. However, due to the high barriers to entry and high operating costs, fluctuating market commodity prices can easily render a mine bankrupt or extremely profitable on the supply side. Market commodity prices are thus outside the control of the mine, and mine supply and market demand will not change significantly due to commodity prices.

(a) Stagnant or falling commodity prices have put pressure on margins and caused mines to become more productive and profitable in order to remain in the market (Lane et al., 2015). (Basis for causal relationship 7) in section 3.4.2)

A prolonged downturn of platinum and gold markets have caused investors to pressurise non-profitable mines to increase their margins (Antin, 2013) and due to being a labour-intensive industry, mines have kept wages low and even shed jobs.

(b) Amplats saw prolonged strikes, where labour unions were requesting above-inflation rate increases and this is likely to occur further in the industry (Antin, 2013). (Basis for causal relationship 8) in section 3.4.2)

2.1.6. Industrialisation and Urbanisation

The global trend of industrialisation and urbanisation is likely to sustain demand for resources in the long term (Lane et al., 2015). China’s urbanisation has driven global demand for iron ore, as an example, which has significantly influenced the SA iron ore supply.

(a) SA became the most industrialised country in Africa in the late 1900's, after major gold and diamond discoveries, which led to a surge in economic growth and investments into the industry (Antin, 2013). (Basis for causal relationship 9) and 10) in section 3.4.3)

2.1.7. Global Economic Recovery

Since the global economic crisis in 2008, important economies such as the USA, Europe and China have been slow to recover (Lane et al., 2015). This has slowed the rate of industrialisation in China and other countries and market commodity prices have fallen due to low demand (Lane et al., 2015).

(a) The global economic recession from 2008 also had a negative impact on GDP, as SA is a net exporter and investment attractiveness, due to more risk averseness until 2011 (Antin, 2013). (Basis for causal relationship 11) and 12) in section 3.4.4)

2.1.8. Africa Attractiveness

The African continent is still regarded as the 'final frontier' which will sustain the world's mineral supply when other continents' supply decline in the future. The relatively low exploration expenditure in Africa, of US$5 per square kilometre, compared to US$65 per square kilometre in Canada, Australia and Latin America (Lane et al., 2015), gives rise to the sentiment that Africa still holds a vast amount of untapped mineral deposits.

(a) SA, being the most industrialised country in Africa (Antin, 2013), is viewed as a gateway to the rest of Africa and therefore many operations would receive strategic investment that enables access to other African mines. (Basis for causal relationship 13) in section 3.4.5)

2.1.9. Regulatory Environment Uncertainty

The effect of regulation on SA mines is a major influencer. Changes in parliament, policy making and public sentiments can impact the way mines are operated.

(a) An increasingly uncertain regulatory environment has caused mines to relook how best to manage profitability, instead of volumes, due to the increased risk of operating in SA (Lane et al., 2015). (Basis for causal relationship 14) in section 3.4.6)

(b) Political instability and the insecurity from an uncertain Mining Charter in 2017 and 2018 is impacting investment negatively (Antin, 2013). (Basis for causal relationship 15) in section 3.4.6)

(c) Uncertainty in the regulatory and political environment has negatively impacted the Rand exchange (Antin, 2013). (Basis for causal relationship 16) in section 3.4.6)

2.1.10. Government Demands

The socio-economic expectations of mining companies have changed in the last century as communities and governments require mining companies to play a larger role in employment, education and healthcare facilities. A mine's success is no longer only measured by GDP or its payment of royalties to the fiscus (Lane et al., 2015). Often when progress on these corporate social responsibility (CSR) actions is slow or halted, labour strikes and production delays may result, causing lower profitability or reputational damage. The annual 'strike season' shows how unions and labourers may not fully appreciate their overall impact on the economy and industry. The onus on mines to conduct CSR initiatives has therefore grown to exceed what is required by law, to a point where society may determine the success or failure of the mine.

(a) Governments are increasingly expecting mines to play a larger role in society, as drivers of employment, socio-economic transformation and other corporate social responsibilities (Lane et al., 2015). This places additional pressure on mines to be profitable, due to more expenses and responsibility than only economic terms. (Basis for causal relationship 17) in section 3.4.7)

(b) Also, when communities feel these expectations are not met, labour unrest is often the result (Lane et al., 2015). (Basis for causal relationship 18) in section 3.4.7)

(c) Government demands are often not required by law, but the perception exists that these intentions will relate to lawful policies in future, thus creating more uncertainty about the regulatory environment in which mines operate. (Basis for causal relationship 19) in section 3.4.7)

2.1.11. Labour Unrest

SA has in the past been riddled with strikes and labour unrest in the mining industry, with unions exerting major power over mining companies by halting labour production for prolonged periods of time, e.g. the 5-month strike at platinum mines from late 2014 signalled the longest and most expensive strike in SA history (Antin, 2013).

(a) The killing of 34 mineworkers by police during a strike at Lonmin's Marikana platinum mine in 2012 caused the Rand to weaken against the Dollar (Alexander, 2013) Also, the economy was shaken by township revolts in 1984 and 1985, causing a strong depreciation of the Rand" (Nattrass, 1995). (Basis for causal relationship 20) in section 3.4.8)

(b) In addition, R15 billion were lost in sales and production due to "wildcat" and other strikes in the gold, platinum and iron ore mines in the country, which hampers economic growth and puts additional pressure on mines to become more profitable (Antin, 2013). (Basis for causal relationship 21) and 22) in section 3.4.8)

(c) The labour situation in SA is also scaring investors away (Antin, 2013). (Basis for causal relationship 23) in section 3.4.8)

2.1.12. Pressure on Margins

With the global situation only having showed early signs of increasing demand and commodity prices from November 2017, SA mining companies have needed to become more efficient and profitable to remain in business with low market demand and falling prices (Lane et al., 2015). The focus on productivity has risen, but is matched by evermore difficult mining conditions, such as deepening depths before reaching deposits, declining ore grades and less frequent new mining discoveries. These conditions result in higher operating costs and render more mining projects infeasible, which hampers the economic growth of SA (Lane et al., 2015). The difficult mining conditions of deteriorating ore grades, less deposit discoveries and deepening excavations to unearth saleable ore have put pressure on mines in SA to transform and focus on productivity (Lane et al., 2015).

(a) Being a labour-intensive industry, the rising input costs of labour and energy, coupled with falling commodity prices and demand, have resulted in major layoffs and operational cost reductions during the past decade (Antin, 2013). This has caused an increase in labour unrest, characterised by the annual “strike season” in SA. (Basis for causal relationship 24) in section 3.4.9)

(b) When margins are under pressure, mines often adopt a “survival strategy” where costs are cut, such as labour, impacting on GDP growth through unemployment, or socio-economic initiatives, causing government demands to go unheeded (Lane et al., 2015). (Basis for causal relationship 25) and 26) in section 3.4.9)

Alternatively, mines may adopt a “leadership strategy”, thus looking for opportunities and making a step change in performance, which may retain the integrity of the mine’s financial position during a downturn (Lane et al., 2015).

2.1.13. Export Revenue

Mining is a foreign exchange earner, with 50% of total SA merchandise exports (Antin, 2013).

(a) When the Rand weakens against the Dollar, mining exports are sold for more revenue, therefore reducing pressure on margins (Antin, 2013). (Basis for causal relationship 27) in section 3.4.10)

(b) Also, downgrades of the Rand by credit rating agencies have impacted the uncertainty surrounding regulatory policies and investor confidence negatively (Antin, 2013). (Basis for causal relationship 28) and 29) in section 3.4.10)

2.1.14. Foreign Direct Investment

25% of total annual investments are related to the mining industry and mining shares account for 29% of the total value of the JSE (Antin, 2013).

(a) Foreign direct investment (FDI) is an external injection into the economy and enables economic growth, as per Keynesian economics theory (Gordon, 1990). (Basis for causal relationship 30) in section 3.4.11)

The capital received from investors also assist mines to implement strategic projects which positions the mine for future value and mitigates risks.

(b) Often, these strategic projects relate to expansion (“brown fields”) or new (“green fields”) projects and ensures export revenues over the long term, as well as higher margins (Antin, 2013). (Basis for causal relationship 31) and 32) in section 3.4.11)

2.1.15. GDP Growth

Gross Domestic Product (GDP) growth is a measure of the total production by SA year-on-year. Financial and legal services which were started to support the mining sector account for 20% of GDP. Also, mining companies alone paid 17.2% of total corporate taxes, which contributes to the multiplier effect of the economy. Direct employment has also ranged between 400k to 700k in the past 15 years, as well as downstream industries' employment (Antin, 2013).

(a) During a negative GDP growth of -2% in 2009 and due to falling commodity prices and demand during the recession from 2008 to 2011, investments became conservative, margins came under pressure and labour disputes surfaced (Antin, 2013). (Basis for causal relationship 33) and 34) and 35) in section 3.4.12)

2.1.16. Section Conclusion

This section has provided the definition of the SA mining industry ecosystem, with 12 concepts and 35 causal relationships that form the basis for defining the FCM's nodes and links in section 3. It is evident that SA mining companies are under pressure from a decline in demand and rising input costs, such as labour and energy costs which have exceeded inflation (Lane et al., 2015) and need to make strategic decisions that will serve to sustain their operations in the long-term as mining requires long-term investment and strategic planning (Lane et al., 2015).

2.2. Strategic Foresight and Scenario Planning

2.2.1. Section Introduction

The purpose of this section is to describe the concepts of strategic foresight and scenario planning so that the systems understanding of the SA mining industry discussed in section 2.1 and the technique of FCM discussed in section 2.3 is contextualised as interfacing bodies of knowledge that complement each other towards an integrated approach for building long-term scenarios.

This section provides an overview of strategic foresight (section 2.2.2) and its subset, scenario planning (section 2.2.3), as a technique that assists SA mines to plan for the long-term future and ensure their strategies are robust and resilient. Scenario planning is integral to the identification of KDFs and the systemic understanding of the SA mining industry, as discussed in section 2.1.

2.2.2. Strategic Foresight

Strategic foresight is about making decisions that will maximise an organisation's chance of success (Lane et al., 2015). No one can tell the future precisely, but organisations still need to envision future discontinuities and develop strategies that will position them optimally, i.e. robust strategies. (Van der Merwe, 2008) describes several phenomena and pitfalls regarding strategic foresight, including predicting based on history, narrow views of the future (i.e. tunnel vision), and overlooking alternative futures.

Systems thinking is an obvious complementor to strategic foresight as it is an approach to complex problems that takes a holistic/ world view of the system components and the causal interrelationships between components. The Iceberg Theory shows that a deeper understanding of surface level events is gained by unpacking patterns of behaviour driving the events and the underlying system structure, assumptions, driving forces and causal relationships (below surface level) (Van der Merwe, 2008). It is key to base strategies not on system events, but on underlying factors in order to ensure robustness and resilience.

Strategic foresight is therefore a non-exact science full of pitfalls which requires scenario planning to creating robust strategies by planning for multiple future scenarios.

2.2.3. Scenario Planning

Scenario planning was based on the works of Herman Kahn (Kahn & Wiener, 1967) and became an applied practice when his protégé, Pierre Wack, developed these techniques in a corporate setting at Royal Dutch Shell in the 1970's (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005) and (Schoemaker & van der Heijden, 1992). The essence of scenario planning revolves around creating multiple future scenarios that are equally likely to occur, using systems thinking and testing the robustness of business strategies within each scenario, coined Wind Tunnelling.

The traditional approach is to identify underlying drivers, or KDFs and select the top two drivers that have the highest uncertainty and importance ranking in relation to the system. These two drivers then form the x- and y-axis, with polar extremes, whereby four quadrants are defined (Amer et al., 2013). Story telling is used to narrate each quadrant's future scenario and wind tunnelling is key to testing organisational strategies against multiple scenarios (Burnam-Fink, 2015) and (Bowman, MacKay, Masrani, & McKiernan, 2013). Robust strategies are successful in all or multiple future scenarios.

The scenarios are monitored by performing trend impact assessments (TIA) on major trends globally, to get a sense of which scenarios are becoming more likely to realise as time lapses (Amer et al., 2013). This approach may assist organisations to adapt their strategies to become more robust and resilient, allocate funds to strategic projects and ensure a competitive advantage in the long term.

Importantly, scenario planning is a qualitative process that makes use of experts' mental models to define the system, KDFs and future scenarios. However, successful scenarios should challenge tunnel vision and shift paradigms by overcoming the naïve tendency to simply extrapolate present trends without considering structural changes and discontinuities (Jetter & Schweinfort, 2011).

(Van der Merwe, 2008) proposes a scenario development framework that involves interviews with experts, workshopping and rigorous analyses, challenging assumptions and stretching logic and finally embedding a continuous process of scenario planning in the organisation. In this systemic thinking approach, KDFs reveal alternative futures, which give rise to relevant research questions, which increases systems understanding (Van der Merwe, 2008).

The quality criteria of scenarios include being relevant, challenging and plausible (Van der Merwe, 2008). Other criteria argued by (Godet, 2000) to ensure rigorous application of scenario planning includes relevance, coherence, plausibility, importance, and transparency.

Scenarios may be built collectively by people of different expertise, background and views who are likely to have different mental models, to prevent groupthink and more effectively read trends that will precede fundamental change (Jetter & Schweinfort, 2011). In conjunction with the qualitative aspects of scenario development, recent research has shown several applications of quantitative methods, such as (Amer et al., 2013):

- Interactive Cross Impact Simulation (INTERAX)
- Interactive Future Simulations (IFS)
- Trend impact analysis (TIC)
- FCM (FCM)

FCM has been cited numerously as being an ideal quantitative technique for scenario development, due to its accommodation of systems thinking in a complex environment or problem.

2.2.4. Section Conclusion

This section described the knowledge area of strategic foresight and scenario planning. Scenario planning is an ideal technique for SA mines to perform strategic long-term decision making (Lane et al., 2015). Traditionally as a qualitative technique, scenario planning has lately been applied to problems using quantitative techniques such as FCM (Amer et al., 2013). The process of scenario planning was followed by (Lane et al., 2015) and (Antin, 2013), as shown in section 2.1, to identify the systemic understanding of the SA mining industry and its KDFs.

2.3. Fuzzy Cognitive Mapping

2.3.1. Section Introduction

The purpose of this section is to describe the quantitative technique of FCM (FCM) and how it can be used to generate scenarios in the SA mining industry.

This section describes how FCM (FCM) developed over time (section 2.3.2). A conceptual and practical description is provided in sections 2.3.3 and 2.3.4 to illustrate how the technique is applied in practice. Finally, the steady-state methodology, selected as the methodology to be used in this research project, is discussed in section 2.3.5.

2.3.2. Historical Development

Causal cognitive maps are evermore being used to develop scenarios and was first introduced by Robert Axelrod in the 1970’s to represent social scientific knowledge (Amer et al., 2013). These maps make use of oval shapes (“nodes”) and arrows (“edges/ links/ connections”) to represent the critical concepts and their causal interrelationships that make up a system. This is typically derived from a diverse set of mental models by experts who understand the system in question from different perspectives (Chermack, 2004). Bart Kosko subsequently furthered Axelrod’s work by inventing FCMs (FCM), which include the capability of modelling complex causal relationships using weighted links (Amer et al., 2013). FCMs overcome several issues associated with Axelrod’s causal cognitive maps, e.g. equal number of positive and negative arrows flowing into one node and difficulty in analysing indirect effects, feedback loops and time lags (Amer et al., 2013).

2.3.3. Conceptual Description

The plot behind any newspaper article, movie, or debate can be visualised by a FCM, by mapping out the underlying logic of concepts and causal relationships.

A key benefit of FCM is that it is non-linear, which assists to model real-world system dynamics. This is mainly due to the accommodation of feedback loops in FCMs, whereas linear models typically only allow for one-directional flow. In linear models, causal input "juice" flowing in at the one side would eventually flow out on the other side, however this does not always illustrate the complex behaviour of real-world systems. Using a FCM, the causal input "juice" flowing in will typically swirl and stabilise in a certain pattern without leaving the system altogether (Kosko & Toms, 1993) and (Kosko, 1986). This pattern is the underlying system behaviour which is often not visible to experts at the surface (events level) and is the key finding from simulating a FCM.

FCMs have been used in a wide range of industries and applications, such as "strategic information system planning, product planning, modelling health care and political issues, assessing the impact of the European monetary union and determining the animation sequences for a cartoon" (Jetter & Schweinfort, 2011).

2.3.4. Practical Description

Simulating a FCM traditionally occurred by turning specific nodes "on" or "off", with a relative value within a specific range and allowing the causal links to influence other nodes in the model. Links are denoted with "+" or "-" signs to indicate the causal relationship between two nodes. A positive sign indicates that a positive increase in the "from" node will result in a positive increase in the "to" node. A negative sign indicates that a positive increase in the "from" node will result in a negative increase in the "to" node (Jetter & Schweinfort, 2011). The strength of these causal relationships are modelled with weights, typically ranging between [-1;1] (Jetter & Schweinfort, 2011), although other ranges and Likert type descriptions may be assigned to classify causal strength. In some cases, varying individual FCMs from experts may be collated and the average causal weight will be calculated to be used in a final FCM. Also, several individual FCMs may also feed into each other, where certain FCMs' nodes feed into other overarching FCMs' nodes (Jetter & Schweinfort, 2011).

A FCM is likened to a neural network, however the neurons don't simply turn "on" and "off", but rather receive a value in the typical range of [-1;1]. Concepts are therefore 'fuzzy' and once "fired" they will influence other concepts in the network, depending on the direction and size of the causal relationships (Jetter & Schweinfort, 2011). Feedback loops in the FCM will cause newly activated concepts to activate other concepts, which may not have been activated by the initial "fired" concepts (defined as Transmitter Nodes in section 3.3.1) and the FCM will settle in a non-linear manner into a new equilibrium pattern (i.e. steady state) (Jetter & Schweinfort, 2011).

Matrix algebra calculations are done to model the activation of nodes throughout the network due to a specific set of "fired" nodes (Stacey, 2016). This is done by listing the status of each node in a matrix, called the "state vector" and multiplying it with the matrix of all causal links' weighted directions, called the "square connection matrix". The result is a new state vector, which represent the new concept nodes' statuses. Also, a "squashing function" is applied to create thresholds for each node, e.g. a binary squashing function will convert all negative values to 0 and all positive values to 1, thus simplifying the FCM's state vector for analysis (Jetter & Schweinfort, 2011).

The state vector is multiplied with the square connection matrix repeatedly until stability is reached or a stop criteria is met (Jetter & Schweinfort, 2011). In the case of an event which may occur periodically or continuously, that node's value in the state vector is clamped to remain unchanged throughout the simulation (Jetter & Schweinfort, 2011).

Ultimately, the FCM is highly sensitive to the structure of the map, causal connections, squashing functions applied and other restrictions or meta-rules imposed (Jetter & Schweinfort, 2011). However, the outcome often remains the same, even though different input state vectors are applied, and this signals that the model is stable. A FCM may have the following outcomes (Jetter & Schweinfort, 2011):

1. **Fixed point:** Several iterations will result in a single node or combination of nodes to be activated, while just as importantly, other nodes are deactivated.
2. **Limit cycle:** A pattern emerges where the model shows a recurring cycle of nodes being activated in a specific sequence. The model will not remain static but will continue predictably within the limits of the pattern.
3. **Chaotic system behaviour:** Continuous FCMs where nodes' state vector values may range in [-1;1] without squashing functions, may experience chaotic system behaviour, with no stabilisation or pattern. This is often the case with large, complex models that contain too many interrelationships to uncover an underlying pattern.
4. **Steady-State:** However, (Stacey, 2016) defines a new way of using FCMs by calculating the inherent steady-state algebraically, therefore doing away with iterations that may be misleading to the modeller. This methodology is the selected approach of this project and is described in section 2.3.5.

2.3.5. Selected Methodology

This research project makes use of a recently cited methodology by (Stacey, 2016) and (Kok, 2009) that shows how to determine the algebraic steady-state of any FCM. Traditionally, a FCM was simulated iteratively and the modeller had to spot patterns, but this methodology had flaws, such as stopping before enough iterations had been run, misreading patterns and long modelling time.

The approach proposed by (Stacey, 2016) is to determine the KDFs of a system, such as the SA mining industry and convert these KDFs into the nodes of the FCM. External nodes that influence the system from outside are called Transmitter Nodes and these can't receive any feedback (input) from other nodes. Internal nodes that can influence other nodes and be influenced by other nodes are called Response Nodes (Stacey, 2016).

Importantly, Transmitter Nodes are defined with specific state vectors (section 3.3.2) that govern the range of possible permutations the FCM can be tested with.

Once the FCM nodes have been defined through a systems thinking approach, the causal relationships between nodes are defined as links in the FCM and denoted with “+” or “-“ signs, indicating a linear or inverse relationship respectively. Next, link weights are assigned to each causal relationship, based on quantitative data from a survey questionnaire, thus making this a semi-quantitative FCM application that is data-driven.

The FCM nodes and weighted links are then converted into an Adjacency Matrix (see section 4.4.1) to enable quantitative simulation of the FCM. Each survey response is simulated individually in the Adjacency Matrix and aggregated statistically to produce the FCM outputs.

It is found that the system converges and stabilises as a result of the link weights between Response Nodes and not Transmitter Nodes (Stacey, 2016), hence the weighting scale must be calibrated to ensure the system remains in control.

Finally, the FCM can be used to generate scenarios and this is where the approach of (Stacey, 2016) is unique, in that it uses an algebraic formula to determine the steady-state of the system, instead of the traditional iterative approach. Scenario planning can now be a data-driven approach using FCM.

2.3.6. Methodology Selection Rationale

Data-driven FCM was selected as the ideal application for this project as fuzzy logic is well suited to model a complex system such as the SA Mining industry. Also, it is not realistic to reduce KDF impacts to specific values, hence the FCM interpretation is relative, not specific. The traditional approach of using two or three KDFs to perform scenario planning, i.e. four quadrants, is also overcome with the FCM approach where a five-dimensional scenario can be developed using the model in this project. This creates more depth of complexity, increases the agility and speed to developing scenarios, and allows for data-driven scenarios, which addresses the Problem Statement (section 1),

2.3.7. Section Conclusion

This section provided an understanding of what FCM is, how it is used and specifically the approach to be followed in this research project.

The use of survey questionnaires to assign link weights makes the FCM data-driven and the selected methodology finds the steady-state of the system instead of the traditional iterative modelling. FCM is a semi-quantitative technique which allows for a vast array of applications, but has been specifically directed towards the area of scenario planning and long term strategy (Jetter & Schweinfort, 2011). Section 3 will now show how this can be applied in the SA mining industry to develop a FCM for scenario planning purposes.

3. THEORETICAL MODEL FORMULATION

3.1. Section Introduction

Section 2 dealt with three main knowledge areas: the SA mining industry and its KDFs (section 2.1), strategic foresight and scenario planning (section 2.2) and FCM (section 2.3). These knowledge areas interface with the scope of the research project and this section is aimed at describing how the combination of these bodies of knowledge may yield solutions to the problem statement stated in section 1.

A final FCM is developed (section 3.5) after defining the system nodes (section 3.3) and causal relationships (section 3.4) found in the SA mining industry.

3.2. The Interface between the South African Mining Industry, Scenario Planning and Fuzzy Cognitive Mapping

Mining companies in SA are faced with ever-increasingly difficult operating conditions and uncertainty about the future, however this capital-intensive industry needs to make long-term decisions as it typically takes long periods of time (i.e. years) for changes to realise any value (Lane et al., 2015).

Scenario planning offers a relevant and effective methodology for mining companies to prepare for the future and act appropriately in the present (Lane et al., 2015). By developing multiple alternatives of the future, SA mines can best manage large investments by ensuring robust and resilient strategies are put in place. Scenario planning is ideal for industries with volatile conditions and high investment barriers, such as mining (Lane et al., 2015). It also allows mines to adopt a forward-looking and divergent thinking approach, which may set them apart from competitors and create a competitive advantage in a highly commoditised industry.

With the application of FCM to scenario planning, a semi-quantitative, data-driven model (as described in section 2.3.5) is generated. This data-driven FCM converts the qualitative mental models of experts through a systems thinking manner into a quantitative model that can be simulated iteratively to produce numerous scenarios and converge to a steady state. FCM may thus allow mining companies to effectively understand the system in which they operate, the future scenarios which may emerge and potential surprises which were not evident before.

It is therefore proposed in this research proposal that the nexus between scenario planning and FCM provides a solution for understanding future scenarios related to the SA mining industry. The following sections will focus on formulating the FCM from the research done in section 2.1.

3.3. System Nodes

As described in section 2.1, the FCM consists of system nodes and causal relationships between nodes. The system nodes are defined from the KDFs that influence the SA mining industry, as discussed in section 2.1.3.

3.3.1. Transmitter Nodes

Transmitter Nodes are external influencers that drive the system and can't receive feedback from other nodes. The five Transmitter Nodes defined by (Lane et al., 2015) as being global influences on mining companies with SA operations are as follows:

1. Resource nationalism (described in section 2.1.4)
2. Market commodity prices (described in section 2.1.5)
3. Industrialisation and urbanisation (described in section 2.1.6)
4. Global economic recovery (described in section 2.1.7)
5. Africa attractiveness (described in section 2.1.8)

3.3.2. State Vectors

As stated in section 2.3.5, Transmitter Nodes are assigned specific state vectors that govern the possible permutations within the FCM. Figure 1 shows the assigned state vectors for each of the Transmitter Nodes. Resource Nationalism and Africa

Attractiveness are defined as nodes that are either “on” (1) or “off” (0) as these nodes either occur or they don’t. Alternatively, Market Commodity Prices, Industrialisation and Urbanisation and Global Economic Recovery as defined as nodes that can either increase (1), remain constant (0), or decrease (-1).

		Resource Nationalism	Market Commodity Prices	Industrialisation and Urbanisation	Global Economic Recovery	Africa Attractiveness
State Vectors	**1**	1	1	1	1	1
	0	0	0	0	0	0
	-1		-1	-1	-1	

Figure 1: Transmitter Nodes State Vectors

3.3.3. Response Nodes

Response Nodes are internal drivers that make up the system and can influence and be influenced by other nodes. Importantly, Response Nodes may have direct feedback loops where a node is influenced by the node it influences.

(Lane et al., 2015) further describes the four local (i.e. internal) KDFs on SA mining operations and these are used to define the Response Nodes of the FCM. The internal input KDFs are as follows:

6. Regulatory environment uncertainty (described in section 2.1.9)
7. Government demands (described in section 2.1.10)
8. Labour unrest (described in section 2.1.11)
9. Pressure on margins (described in section 2.1.12)

Lastly, the mining industry also produces outputs back into the ecosystem which contribute to the SA economy, as described by (Antin, 2013). These three KDFs are classified as internal KDFs and used to define Response Nodes of the FCM. The internal output KDFs are as follows:

10. Export revenue (described in section 2.1.13):
11. Foreign direct investment (described in section 2.1.14)
12. GDP growth (described in section 2.1.15)

Therefore, 12 concepts are defined from the research to make up the SA mining industry's ecosystem. Five Transmitter Nodes will influence the FCM from outside the ecosystem and affect seven Response Nodes. The concepts are now modelled as nodes in the FCM, illustrated in Figure 2.

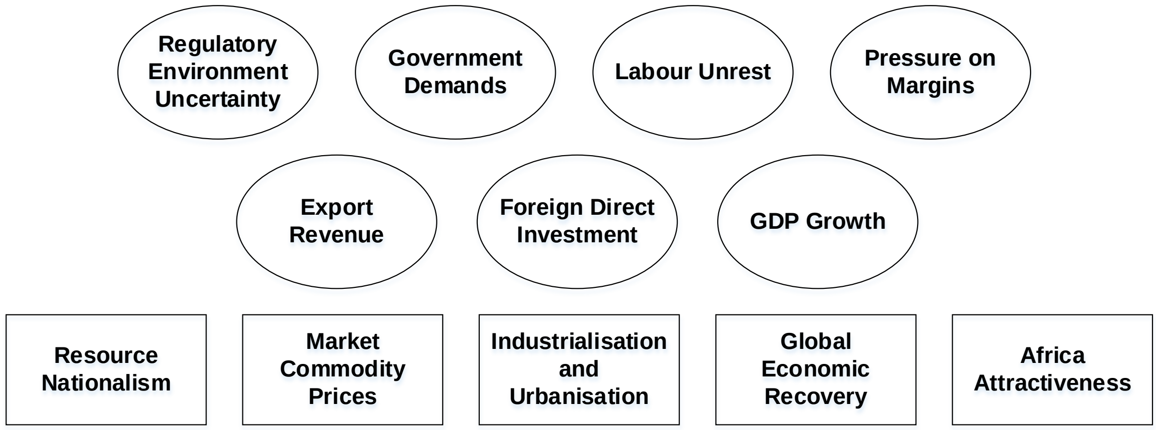

Figure 2: SA Mining Industry Ecosystem Concepts

3.4. Causal Relationships

The causal relationships between nodes are defined in this section from research at the time of the study (section 2.1). Each node is only described in relation to the causal relationships found in the literature review and not in relation to all other 11 concepts for simplicity sake. Importantly, Transmitter Nodes will have no inflowing relationships as these nodes drive the rest of the system, hence only outflow relationships. Response Nodes may have both inflow and outflow relationships and may even have direct feedback loops with other nodes.

3.4.1. Resource Nationalism

1) An increase in resource nationalism may cause an increase in pressure on margins. (Based on (a) in section 2.1.4)
2) An increase in resource nationalism may cause a decrease in foreign direct investment. (Based on (b) in section 2.1.4)

3) An increase in resource nationalism may cause an increase in government demands. (Based on (c) in section 2.1.4) A slight increase is used as a constant in the model, due to no data collected for this relationship. This assumption equates to a factor of +0.15 after calibration (section 4.4.2)
4) An increase in resource nationalism may cause an increase in regulatory environment uncertainty. (Based on (d) in section 2.1.4) A moderate increase is used as a constant in the model, due to no data collected for this relationship. This assumption equates to a factor of +0.3 after calibration (section 4.4.2)
5) An increase in resource nationalism may cause a decrease in export revenue. (Based on (b) in section 2.1.4)
6) An increase in resource nationalism may cause a decrease in GDP growth. (Based on (b) in section 2.1.4)

The causal relationships related to resource nationalism are illustrated in Figure 3:

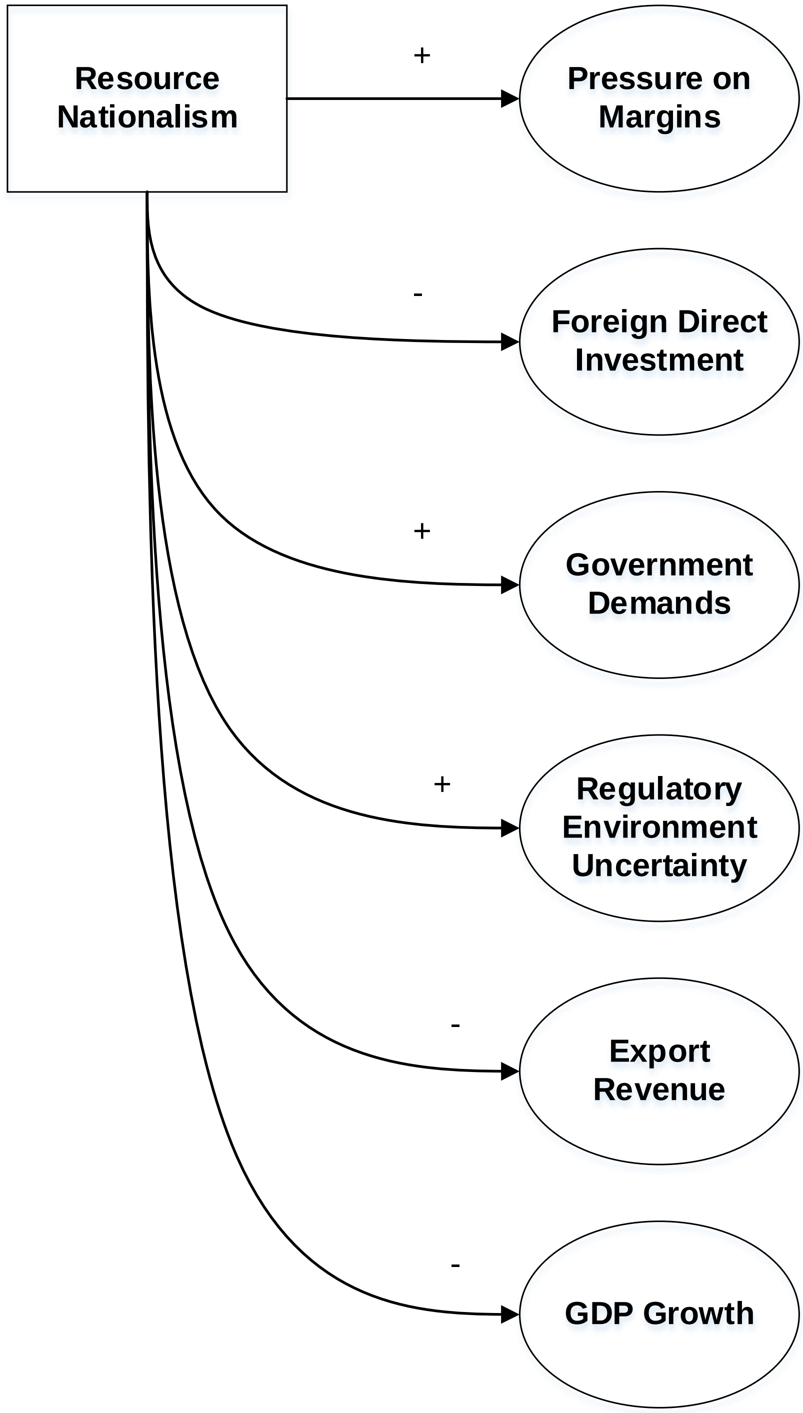

Figure 3: Resource nationalism causal relationships

3.4.2. Market Commodity Prices

7) An increase in market commodity prices may cause a decrease in pressure on margins. (Based on (a) in section 2.1.5)
8) An increase in market commodity prices may cause a decrease in labour unrest. (Based on (b) in section 2.1.5)

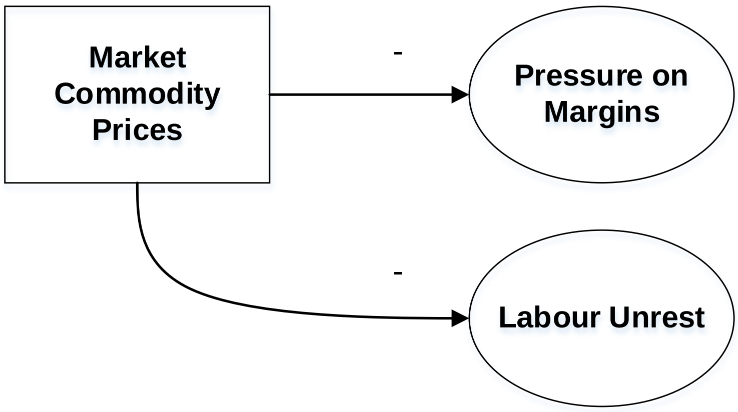

Figure 4: Market commodity prices causal relationships

3.4.3. Industrialisation and Urbanisation

9) An increase in industrialisation and urbanisation may cause an increase in GDP growth. (Based on (a) in section 2.1.6)
10) An increase in industrialisation and urbanisation may cause an increase in foreign direct investment. (Based on (a) in section 2.1.6)

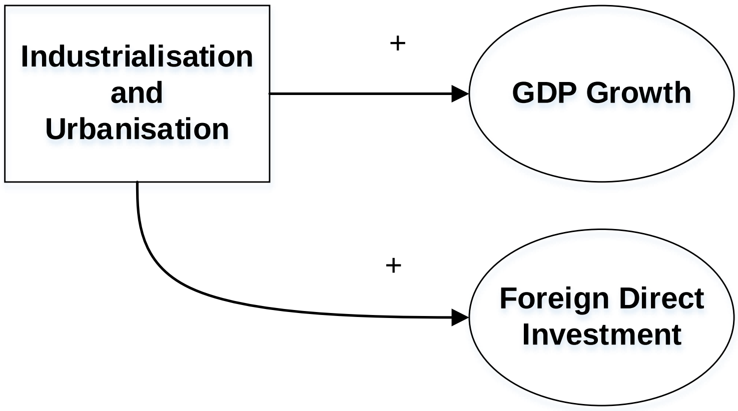

Figure 5: Industrialisation and urbanisation causal relationships

3.4.4. Global Economic Recovery

11) An increase in global economic recovery may cause an increase in GDP growth. (Based on (a) in section 2.1.7)

12) An increase in global economic recovery may cause an increase in foreign direct investment. (Based on (a) in section 2.1.7)

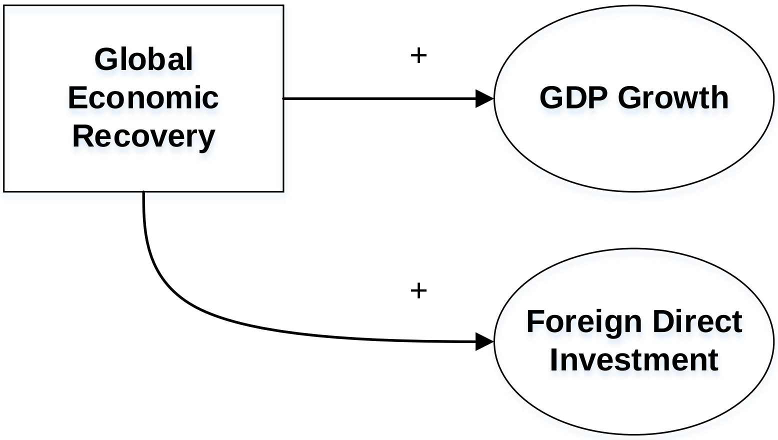

Figure 6: Global economic recovery causal relationships

3.4.5. Africa Attractiveness

13) An increase in Africa attractiveness may cause an increase in foreign direct investment. (Based on (a) in section 2.1.8)

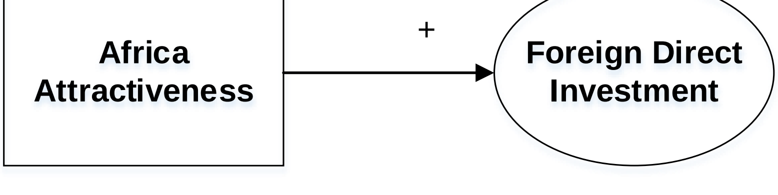

Figure 7: Africa attractiveness causal relationships

3.4.6. Regulatory Environment Uncertainty

14) An increase in regulatory environment uncertainty may cause an increase in pressure on margins. (Based on (a) in section 2.1.9)
15) An increase in regulatory environment uncertainty may cause a decrease in foreign direct investment. (Based on (b) in section 2.1.9)
16) An increase in regulatory environment uncertainty may cause a decrease in export revenue. (Based on (c) in section 2.1.9)

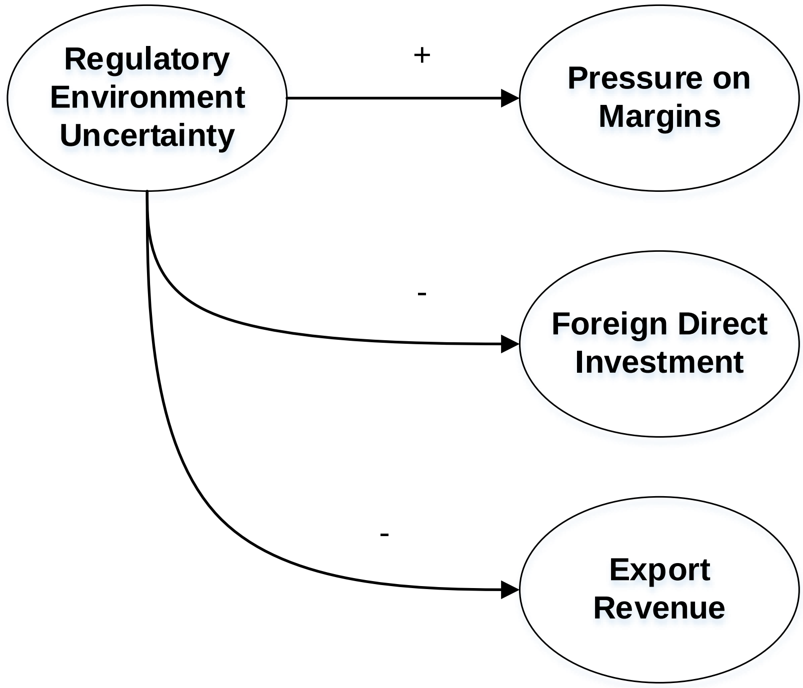

Figure 8: Regulatory environment uncertainty causal relationships

3.4.7. Government Demands

17) An increase in government demands may cause an increase in pressure on margins. (Based on (a) in section 2.1.10)
18) An increase in government demands may cause an increase in labour unrest. (Based on (b) in section 2.1.10)
19) An increase in government demands may cause an increase in regulatory environment uncertainty. (Based on (c) in section 2.1.10)

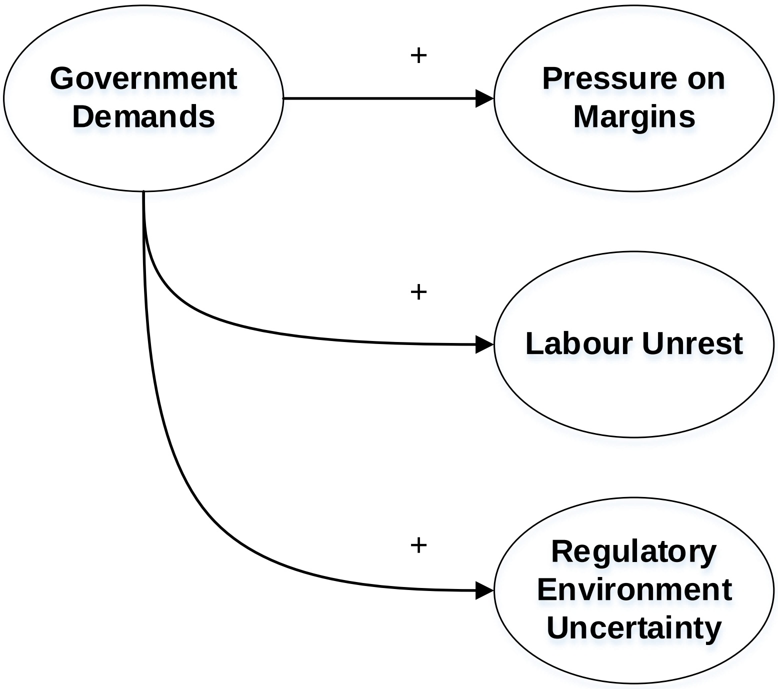

Figure 9: Government demands causal relationships

3.4.8. Labour Unrest

20) An increase in labour unrest may cause a decrease in export revenue. (Based on (a) in section 2.1.11)
21) An increase in labour unrest may cause a decrease in GDP growth. (Based on (b) in section 2.1.11)
22) An increase in labour unrest may cause an increase in pressure on margins. (Based on (b) in section 2.1.11)
23) An increase in labour unrest may cause a decrease in foreign direct investment. (Based on (c) in section 2.1.11)

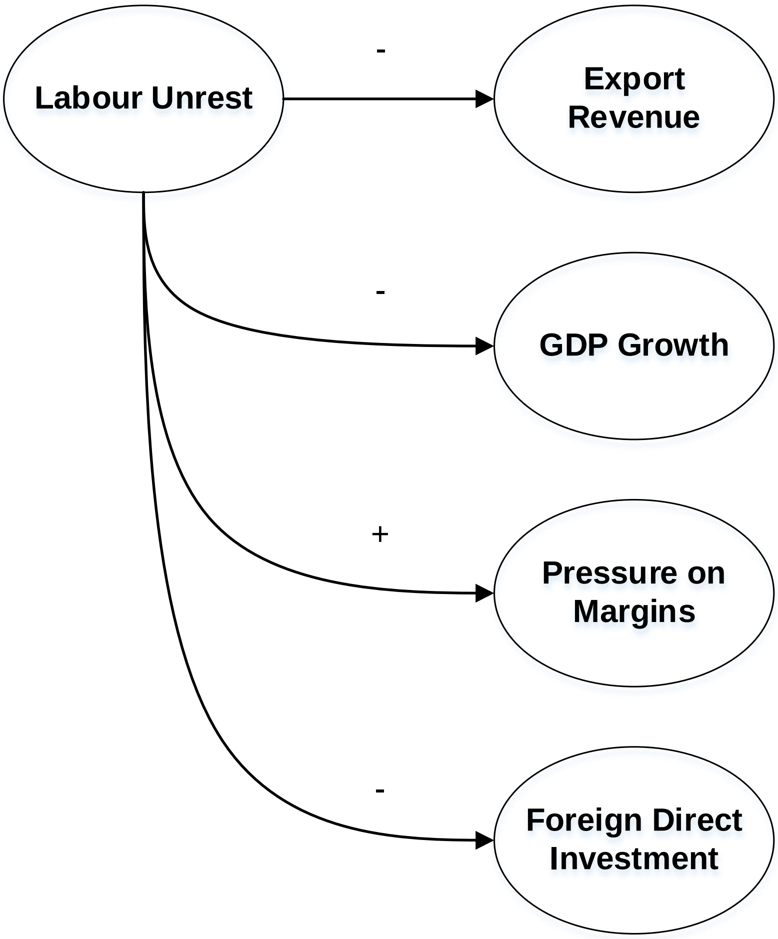

Figure 10: Labour unrest causal relationships

3.4.9. Pressure on Margins

24) An increase in pressure on margins may cause an increase in labour unrest. (Based on (a) in section 2.1.12)
25) An increase in pressure on margins may cause a decrease in GDP growth. (Based on (b) in section 2.1.12)
26) An increase in pressure on margins may cause an increase in government demands. (Based on (b) in section 2.1.12)

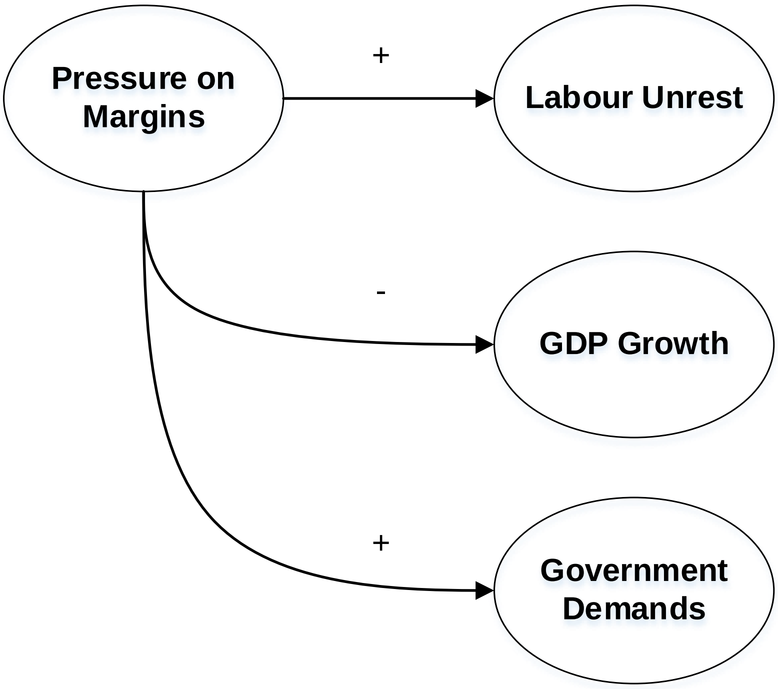

Figure 11: Pressure on margins causal relationships

3.4.10. Export Revenue

27) An increase in export revenue may cause a decrease in pressure on margins. (Based on (a) in section 2.1.13)
28) An increase in export revenue may cause a decrease in regulatory environment uncertainty. (Based on (b) in section 2.1.13)
29) An increase in export revenue may cause an increase in foreign direct investment. (Based on (b) in section 2.1.13)

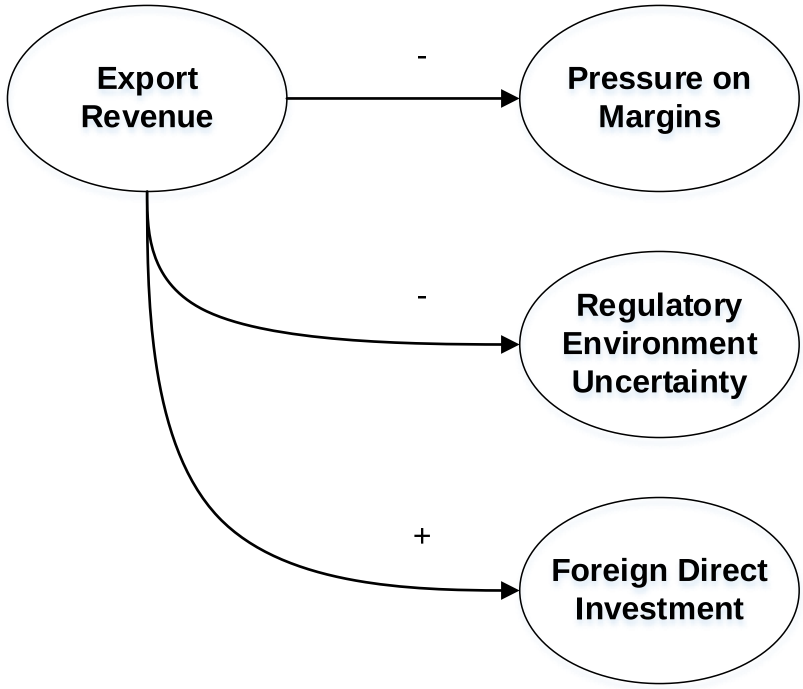

Figure 12: Export revenue causal relationships

3.4.11. Foreign Direct Investment

30) An increase in foreign direct investment may cause an increase in GDP growth. (Based on (a) in section 2.1.14)
31) An increase in foreign direct investment may cause an increase in export revenue. (Based on (b) in section 2.1.14)
32) An increase in foreign direct investment may cause a decrease in pressure on margins. (Based on (b) in section 2.1.14)

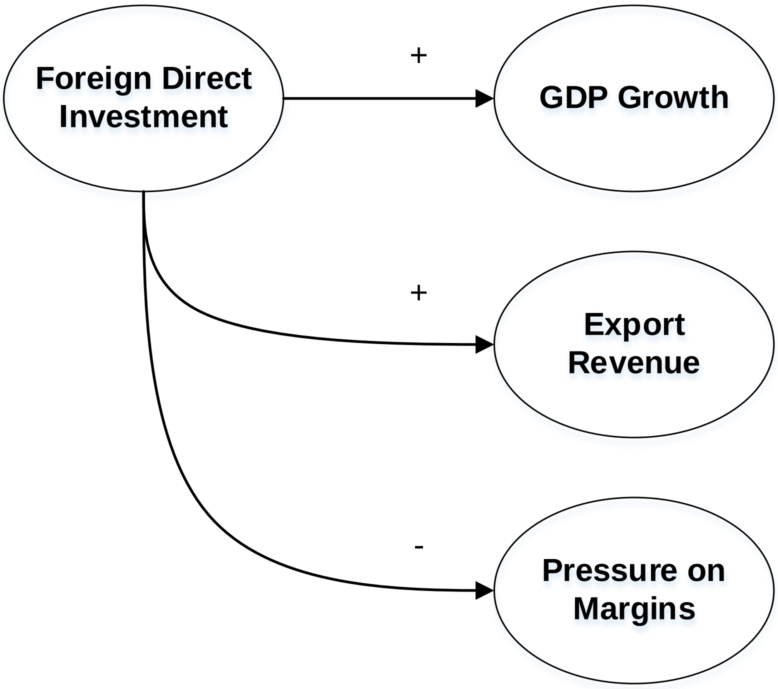

Figure 13: Foreign direct investment causal relationships

3.4.12. GDP Growth

33) An increase in GDP growth may cause an increase in foreign direct investment. (Based on (a) in section 2.1.15)
34) An increase in GDP growth may cause a decrease in labour unrest. (Based on (a) in section 2.1.15)
35) An increase in GDP growth may cause a decrease in pressure on margins. (Based on (a) in section 2.1.15)

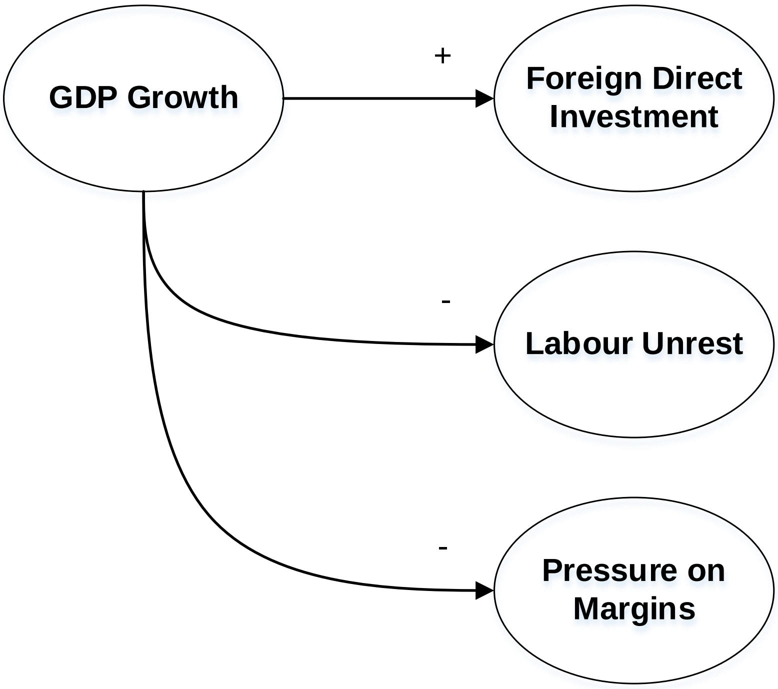

Figure 14: GDP growth causal relationships

3.5. Fuzzy Cognitive Map of South African Mining Industry

The 12 nodes and 35 causal relationships defined in section 2.1 are compiled into a FCM, as in Figure 15. Green links represent positive causal relationships and red links represent negative relationships. Each link is also denoted with either a “+” or “-“ sign. Relationships’ signs don’t represent a “good” or “bad” outcome for the respective nodes, but rather represent positively or negatively correlated nodes.

This visualisation of the mining ecosystem gives an indication which nodes are more influential than others, based on the number of links between nodes. However, the links’ weights may significantly change the outcome and a survey questionnaire is used to provide validation of the causal links’ signs and weights (see section 4).

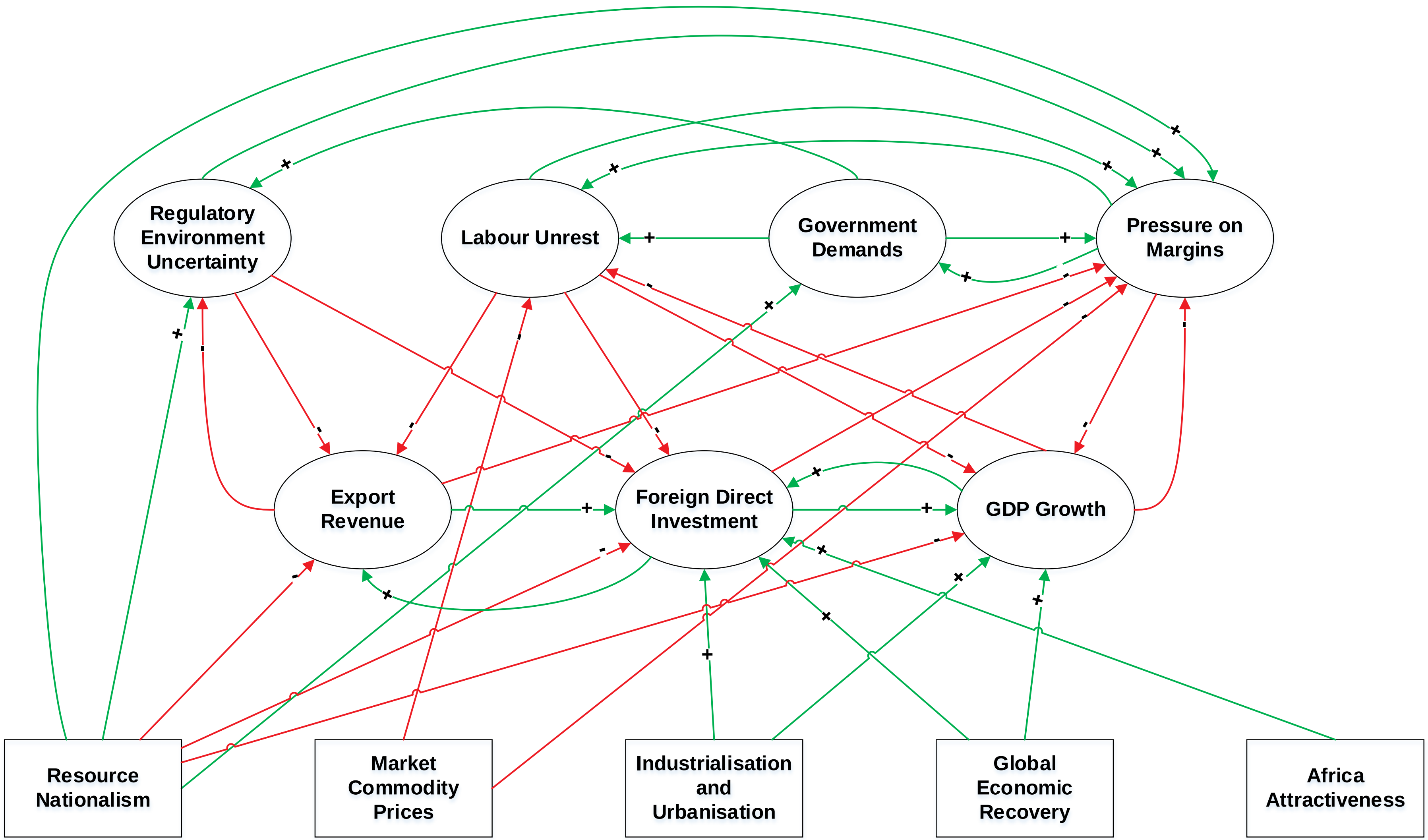

Figure 15: FCM of SA Mining Industry

3.6. Section Conclusion

This section collated the three knowledge areas of section 2 to propose a solution for the problem statement in section 1 by developing a FCM for the SA mining industry. 12 nodes and 35 causal relationships were defined as part of the FCM. It is evident that when combining all the individual causal relationships into a single FCM, it becomes a model which the human brain cannot mimic. Calculations, feedback loops, and permutations can all be done instantly by a simulation, whereas the human brain is only able to compare components of the model at a time. The FCM developed in this project therefore allows mining executives to develop scenarios quickly, at more depths of complexity, and from data – thus satisfying the Problem Statement (section 1).

Section 4 describes the survey questionnaire as the method for data collection and analysis of the dataset. The data was used to assign weights to the causal relationships and the sensitivities of the FCM are analysed.

4. DATA COLLECTION AND ANALYSIS

4.1. Section Introduction

The purpose of this section is to describe how data was collected through a survey questionnaire and to validate the theoretical model formulated in section 3. The survey responses provides a quantitative means of assigning weights to the FCM, validate the direction of the links ("+" or "-") and also validate the hypotheses that these links exist at all.

Section 4.2 describes the rationale for a survey questionnaire to be used (section 4.2.1), a Likert-scale application for responses (section 4.2.2) and the population and sample size determination (section 4.2.3).

Section 4.3 includes the data collection and validation criteria (section 4.3.1) and the qualifying data used for data validation (section 4.3.2).

Section 4.4 describes the data analysis and application of the adjacency matrix (section 4.4.1). Convergence and data aggregation are applied (section 4.4.2) to the adjacency matrix. Sensitivities (section 4.4.3) of the transmitter nodes are also tested and analysed and the dataset is checked for consistency against a subset of experienced respondents (section 4.4.5).

It is noteworthy that 114 mining executives from the SA mining industry opted to partake in this project, of which 73 responses were used. This large data set of experienced and influential individuals with the industry gives great credibility to the model that was developed.

4.2. Data Collection Design Rationale

4.2.1. Method Selection

(Groenewald, 1986) states that five basic research designs exist on a spectrum within two parameters – the type of explanation and the source of data:

1. Types of explanation
    a. Idiographic – single case or event
    b. Nomothetic – multiple cases, events of phenomena

2. Data sources
    a. Direct - observations
    b. Indirect - questionnaires
    c. Documentary

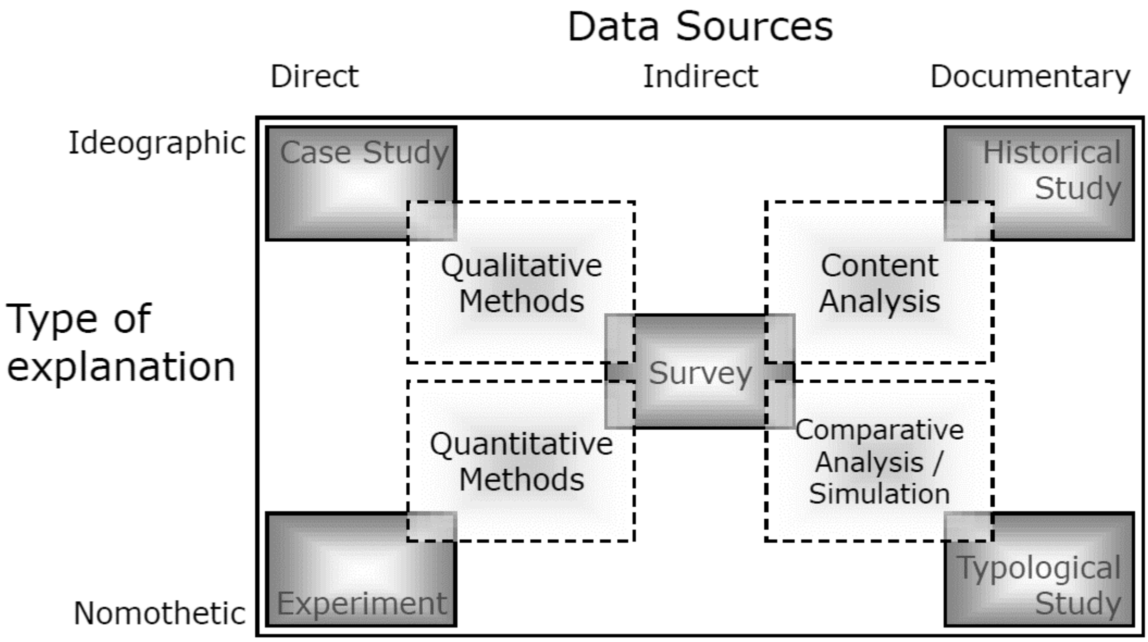

Figure 16: Basic research designs (Groenewald, 1986)

This research project favours a quantitative method of data collection due to it being the key difference from traditional scenario planning, which is mostly qualitative in nature (i.e. interviews with industry experts). Objectivity is sought when assigning link weights to ensure validity of the FCM, hence a quantitative approach is preferred (i.e. the interviewer does not influence the data collection process, as with qualitative methods). Also, an indirect method is preferred due to the short time frame available for data collection. Therefore, according to the framework by (Groenewald, 1986), a survey questionnaire was selected as the method of data collection as it enables a wide breadth of respondents to be reached in a short time frame, thus ensuring validity and reliability. The selected methodology proposed by (Stacey, 2016) further also proposes a data-driven FCM using survey questionnaires.

4.2.2. Likert Scale

The survey questions included a Likert-type response scale, where seven response options were available to the respondent as such:

Table 1: Likert-type survey response options

Available Response Options to Select From						
A	**B**	**C**	**D**	**E**	**F**	**G**
Strong Decrease	Moderate Decrease	Slight Decrease	No Influence	Slight Increase	Moderate Increase	Strong Increase

4.2.3. Population and Sample

This research project includes all stakeholders that have an interest in the SA mining industry. These stakeholders may include:

1. Employees of a mining company in SA
2. Suppliers of goods or services to SA mines, or upstream industries
3. Customers of goods or services from SA mines, or downstream industry
4. SA mining investors and economists
5. SA mining regulators and policy makers
6. Communities impacted by the SA mining industry

However, it is assumed for the purposes of the requirements of the MBA research report that the survey population is scoped as only including persons on executing management level as the nature of the survey questions are such that only executive managers will fully grasp the SA mining industry system as a whole and be able to provide sensible responses. The definition of mining executives is used further in this section and refers specifically to persons with over 20 years' experience and work on an executive managerial level in the SA mining industry. The number of mining executives is based on the membership of the Association of Mine Managers SA (AMMSA) and is currently 825 (AMMSA, 2018), which constitutes the population size. The sample size is therefore calculated as 30 using the following assumed parameters (Select Statistical Services, 2018):

- Population size: 825
- Margin of error: 5%
- Confidence level: 95%
- Sample proportion: 98%
- Recommended sample size: 30

The formula used to determine the sample size n is:

n = N*X / (X + N – 1), where
X = Zα/22 -*p*(1-p) / MOE2

Zα/2 is the critical value of the Normal distribution at α/2 and MOE is the margin of error, p is the sample proportion and N is the population size (Select Statistical Services, 2018).

4.3. Data Collection

A data-driven FCM is applied in this study, as prescribed by (Stacey, 2016) and proposes that the FCM be developed from qualitative inferences, such as research, interviews, etc. This step only accounts for the definition of concept nodes and causal relationships, thus the weighting (range between -1 and +1) and direction (positive or negative) of causal links is found from a quantitative survey questionnaire completed by industry stakeholders. This then makes the FCM a semi-quantitative technique whereby scenarios can be generated from multiple combinations of the Transmitter Nodes' state vectors, as defined in section 3.3.2.

4.3.1. Data Validation

The survey questionnaire was completed by respondents anonymously online and consisted of three qualifying questions for data validation and 33 focused questions for analysis. Only respondents in SA mining companies in executive management positions were requested to complete the survey and the completion of the survey was voluntary, with no obligations. Table 2 shows the number of responses and data validation applied to the dataset. Requests were sent to 759 mining executives, of which 660 were delivered, 141 were opened, and 114 responses were received. A final dataset of 73 responses was used for analysis, as these responses were consented and complete, were relevant to the SA Mining Industry and had sufficient experience. It is notable that the final dataset of 73 responses is a sufficient sample size to represent the population group of 30, as determined in section 4.2.3.

Table 2: Data Validation

Data Validation Criteria	Responses Received	Responses Removed
Total Responses	114	-
Consented Responses	113	(1)
Relevant Industry Responses	102	(11)
Sufficient Experience Responses	98	(4)
Completed Responses	73	(25)
Final Dataset	**73**	**(41)**

4.3.2. Qualifying Data

Three qualifying questions were asked in the survey questionnaire – consent, industry relevance and sufficient experience – to ensure respondents form part of the population group. Figure 17 and Table 3 show the number of consented responses.

The question states: "*Do you consent to completing this survey? There is no obligation or expectation for completing this survey and if the respondent chooses to continue it is of their own choice.*"

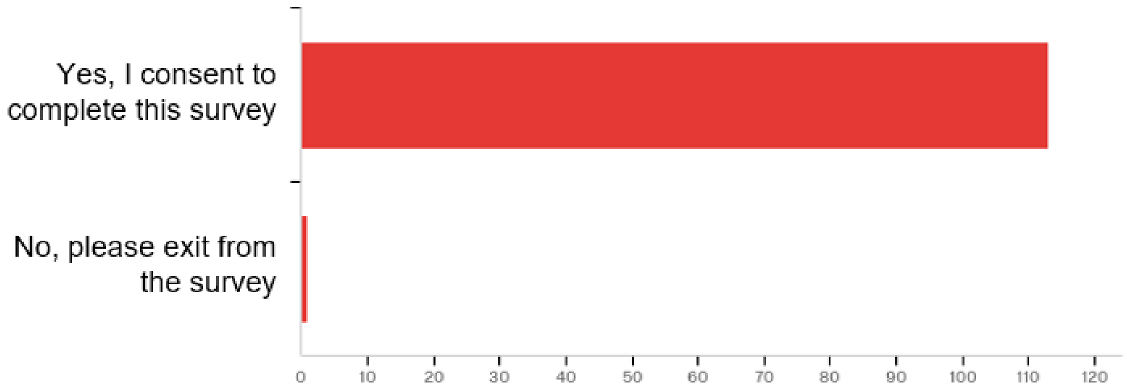

Figure 17: Consented Responses

Table 3: Consented Responses

#	Answer	%	Count
1	Yes, I consent to complete this survey	99.12%	113
2	No, please exit from the survey	0.88%	1
	Total	**100%**	**114**

Figure 18 and **Table 4** show the number of relevant industry responses and Table 5 shows descriptions provided in the "Other" category.

The question states: “*How is your work related to the SA mining industry?*” Note that this is a multiple select question.

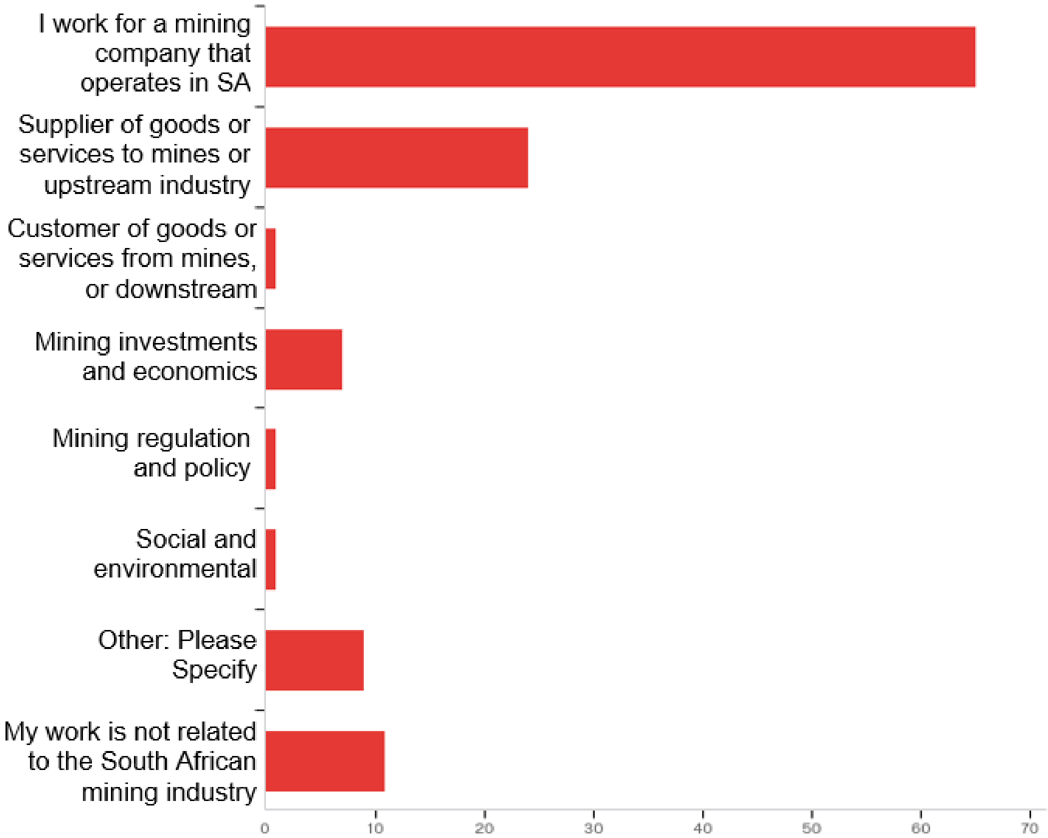

Figure 18: Relevant Industry Responses

Table 4: Relevant Industry Responses

#	Answer	%	Count
1	I work for a mining company that operates in SA	54.62%	65
2	Supplier of goods or services to mines, or upstream industry	20.17%	24
3	Customer of goods or services from mines, or downstream industry	0.84%	1
4	Mining investments and economics	5.88%	7
5	Mining regulation and policy	0.84%	1
6	Social and environmental	0.84%	1
7	Other: Please Specify	7.56%	9
8	My work is not related to the SA mining industry	9.24%	11
	Total	**100%**	**119**

Table 5: Relevant Industry Responses – Other Category

Other: Please Specify - Text
Junior exploration
Project Management consultant to mining industry in SA as well as Africa
Uranium mining in Namibia
Software Vendor
Work in Namibian Mining Industry
Work as Contracts Manager for an EPCM company specializing in Mining
I am a Mineral Economist working as a Consultant for the Coal Mining Industry
Mining Consultancy
I work for a mining company that operates in Mozambique

Figure 19 and Table 6 show the number of relevant industry responses.

The question states: "*How many years' experience do you have in the mining industry?*"

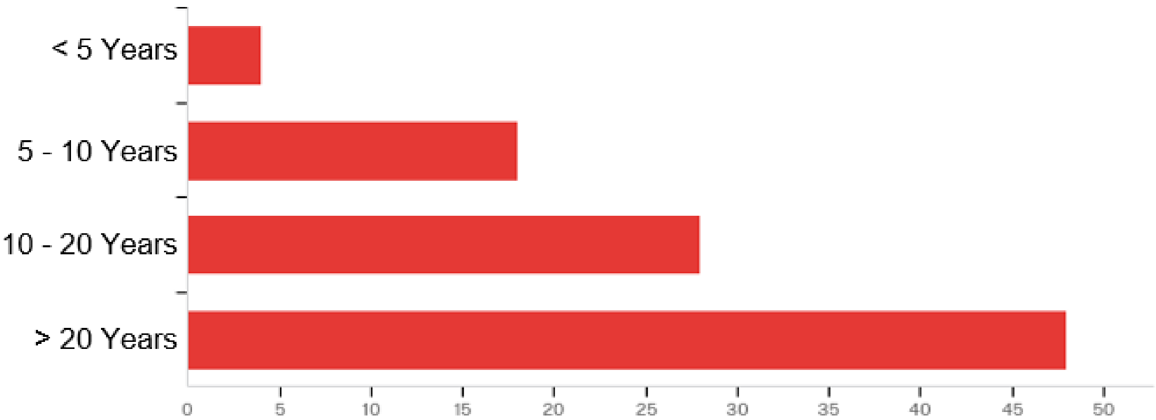

Figure 19: Sufficient Experience Responses

Table 6: Sufficient Experience Responses

#	Answer	%	Count
1	< 5 Years	4.08%	4
2	5 - 10 Years	18.37%	18
3	10 - 20 Years	28.57%	28
4	> 20 Years	48.98%	48
	Total	**100%**	**98**

4.4. Data Analysis

4.4.1. Adjacency Matrix

The adjacency matrix converts the FCM into a quantitative model (Stacey, 2016) with values in the range [-1;+1] to represent the strength and direction of the casual relationships between nodes. Figure 20 shows the causal relationships defined in section 3.4 as grey cells, whereas all other cells are orange, representing no causal relationship. The row heading to the left of the grey cell is the “from” node and the column heading to the top of the grey cell is the “to” node – for example, Market Commodity Prices (row heading) influences Labour Unrest and Pressure on Margins (column headings) as defined in section 3.4.2.

The transmitter nodes can’t be influenced by any other node, by definition, as shown in the first five columns. The steady state of the adjacency matrix is calculated using matrix algebra by (Stacey, 2016) and is determined by the state vectors of the transmitter nodes in the first five columns.

Note that the values shown in Figure 20 represents the Expected Best Case scenario in Section 5.3.

Adjacency Matrix

	Resource Nationalism	Market Commodity Prices	Industrialisation and Urbanisation	Global Economic Recovery	Africa Attractiveness	Regulatory Environment Uncertainty	Government Demands	Labour Unrest	Pressure on Margins	Export Revenue	Foreign Direct Investment	GDP Growth
Resource Nationalism						+0.30	+0.15		-0.15	-0.30	-0.50	-0.30
Market Commodity Prices								+0.15	-0.30			
Industrialisation and Urbanisation			Transmitter nodes									+0.15
Global Economic Recovery											+0.30	+0.30
Africa Attractiveness											+0.30	
Regulatory Environment Uncertainty									+0.15	-0.30	-0.50	
Government Demands						+0.30		+0.50	+0.30			
Labour Unrest									+0.30	-0.15	-0.50	-0.30
Pressure on Margins			Normal and Receiver Nodes				-0.15	+0.15				
Export Revenue									-0.15		+0.15	
Foreign Direct Investment										+0.15		+0.30
GDP Growth								+0.15			+0.30	
Steady State:	0	1	1	1	1	0.01042	0.03473	0.22035	-0.23155	0.06428	0.6697	0.5848

Figure 20: FCM Adjacency Matrix

4.4.2. Convergence and Data Aggregation

The 73 survey responses described in section 4.3 were modelled individually in the adjacency matrix with a data table – each respondent's set of responses were modelled, and 73 steady states were determined. Statistics are therefore done on the outputs from the model, i.e. 73 steady states and not on the inputs to the model, i.e. distribution of responses on one causal relationship. Also, to ensure convergence of the FCM's steady state and that the Eigen values of the model are less than 1 (i.e. stable), the convergence factors in Table 7 were used to represent the Likert scale response values and to calibrate the model. These convergence factors were determined through an iterative process, starting from a wider range of [-1;1], which did not reach steady state (diverging) and selecting ever-smaller convergence factors until the proposed range of [-0.5;0.5] in Table 7 found that the model converges and reaches steady state.

Table 7: Convergence Factors

Likert Scale	Response Value	Convergence Factor
Strong Decrease	1	- 0.50
Moderate Decrease	2	-0.30
Slight Decrease	3	-0.15
No Influence	4	0.00
Slight Increase	5	0.15
Moderate Increase	6	0.30
Strong Increase	7	0.50

4.4.3. Sensitivities

The sensitivity of the Response Nodes to the Transmitter Nodes have been tested individually, per Transmitter Node, to determine which are the top drivers in the system and to what extent.

Figure 21 illustrates the median values of the adjacency matrix data table per transmitting node, i.e. one transmitting node state vector is set to "1" and all others is set to "0". The magnitude of the nodes from the "0"- line in **Figure 21** indicates the perturbation and median steady state as a sensitivity to a specific transmitting node's external influence. Values to the right indicate a positive ("+") perturbation and values to the left indicate a negative perturbation ("**-**").

From **Figure 21** it becomes evident that the system is most sensitive to Resource Nationalism and least sensitive to Market Commodity Prices. Global Economic Recovery is second most sensitive, followed by Industrialisation and Urbanisation and then Africa Attractiveness.

These sensitivities have face validity, except Market Commodity Prices which is the least influential driver – this is counter-intuitive for the mining industry. Only considering median values, as in **Figure 21**, does not provide enough statistical insight, therefore **Figure 22** shows the boxplot ("box and whiskers") of each sensitivities, with 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values. From this analysis, it can again be concluded that Resource Nationalism is the most influential driver, followed by Global Economic Recovery and then Industrialisation and Urbanisation. However, Market Commodity Prices is seen to have a wider distribution in certain nodes, although the median may be close to "0" and therefore it is regarded as more sensitive than Africa Attractiveness.

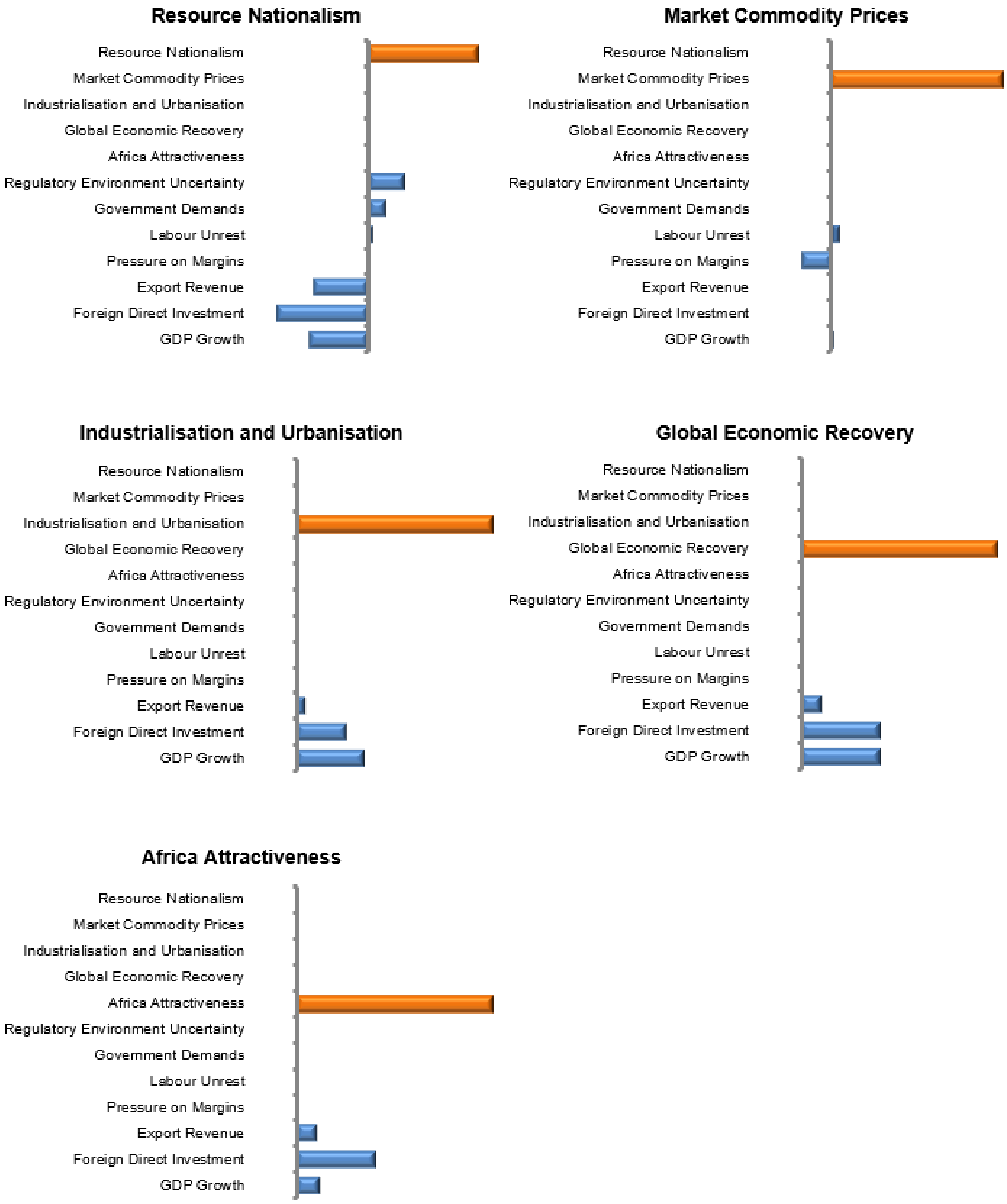

Figure 21: Sensitivities (Median)

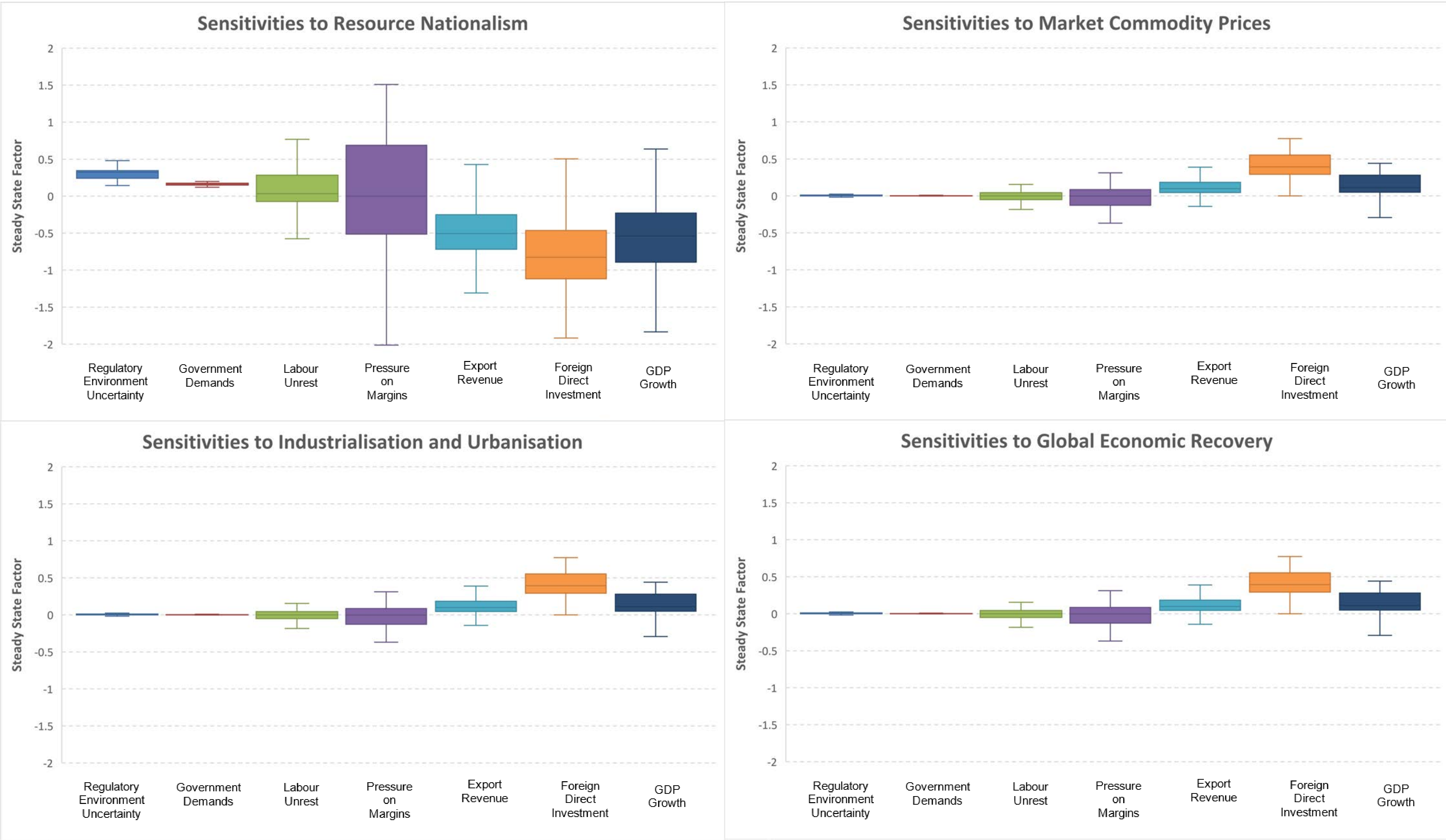

Figure 22: Sensitivities (Boxplot)

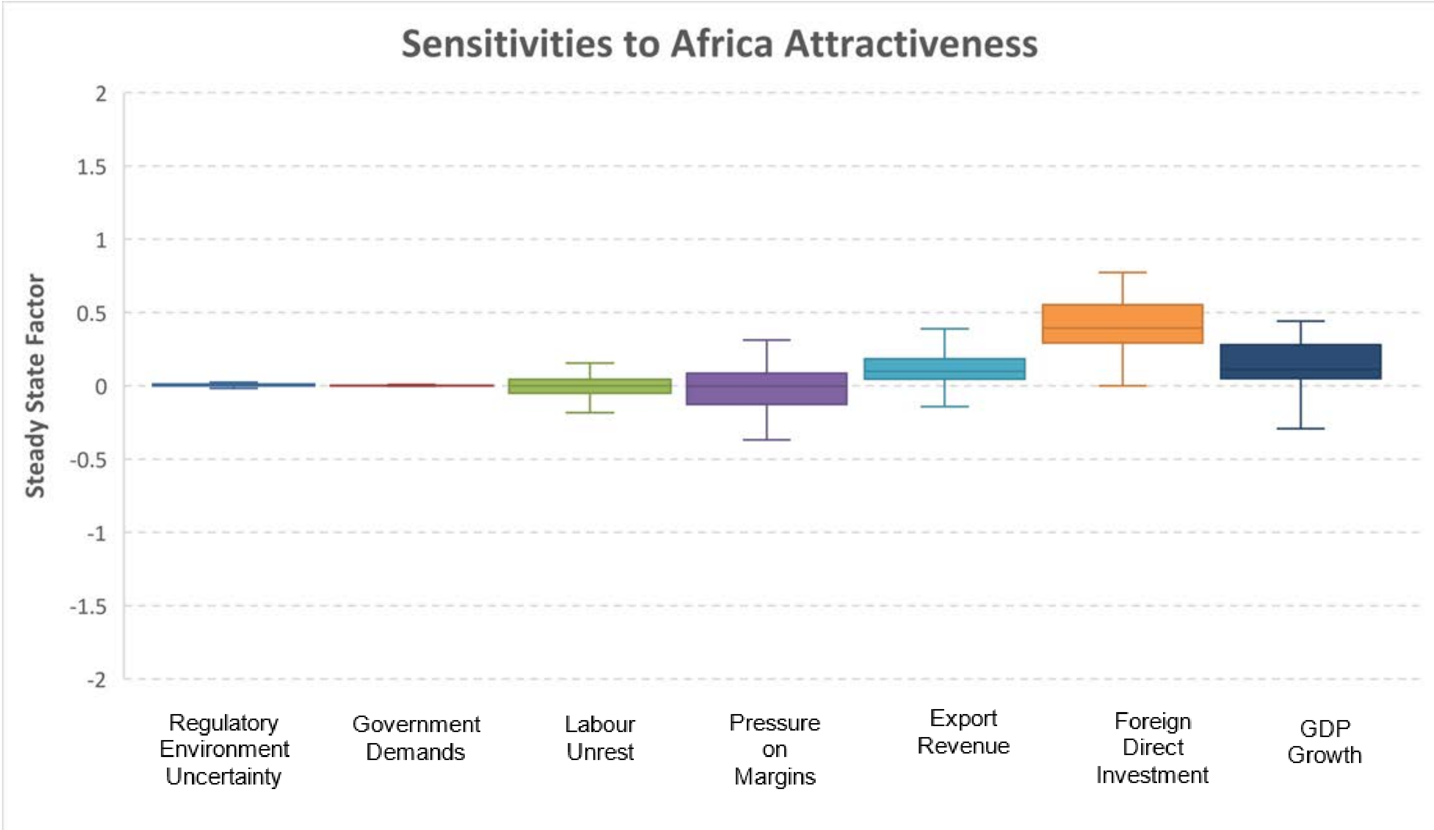

Figure 22 (Continued): Sensitivities (Boxplot)

From **Figure 21** and **Figure 22** it is also evident that the most erratic nodes in the system are Pressure on Margins, Foreign Direct Investment and GDP Growth. Contrarily, Labour Unrest and Export Revenue have moderate perturbation throughout the sensitivity tests, whereas Regulatory Environment Uncertainty and Government Demands have very minor perturbation.

Also, if positive perturbation ("+") in Export Revenue, Foreign Direct Investment and GDP Growth and negative perturbation ("-") in Regulatory Environment Uncertainty, Government Demands, Labour Unrest and Pressure on Margins is regarded as a 'good thing' for the SA mining industry, then the following conclusions may be made when these external drivers are increasing:

- Resource Nationalism destroys value in the SA mining industry
- Market Commodity Prices can either create or destroy value in the SA mining industry
- Industrialisation and Urbanisation creates value in the SA mining industry
- Global Economic Recovery creates value in the SA mining industry
- Africa Attractiveness creates value in the SA mining industry

4.4.4. Inter-Quartile Ranges

Similarly to the sensitivities described in section 4.4.3, the inter-quartile ranges (variance between 1st and 3rd quartiles) per transmitter node gives statistical insight into how much "agreement" there is in the dataset – the lower the inter-quartile range, the more "agreement" there is.

Figure **23** shows in green colour the nodes with most "agreement", in yellow colour the nodes with moderate "agreement" and in red colour the nodes with the least "agreement". It is evident that Regulatory Environment Uncertainty and Government Demands have the lowest inter-quartile ranges and therefore suffer the least perturbation in the system. Pressure on Margins has the highest inter-quartile range when influenced by Resource Nationalism or Market Commodity Prices. Foreign Direct Investment and GDP Growth has the highest inter-quartile range when influenced by Industrialisation and Urbanisation, Global Economic

Recovery and Africa Attractiveness. Labour Unrest and Export Revenue are always moderately influenced.

Inter-quartile range	Regulatory Environment Uncertainty	Government Demands	Labour Unrest	Pressure on Margins	Export Revenue	Foreign Direct Investment	GDP Growth
Resource Nationalism	0.10	0.02	0.35	1.18	0.45	0.63	0.66
Market Commodity Prices	0.02	0.04	0.27	0.60	0.12	0.21	0.26
Industrialisation and Urbanisation	0.01	0.00	0.16	0.15	0.16	0.47	0.38
Global Economic Recovery	0.01	0.01	0.16	0.26	0.17	0.46	0.38
Africa Attractiveness	0.01	0.00	0.09	0.20	0.14	0.25	0.22

Figure 23: Inter-Quartile Ranges

4.4.5. Dataset Experience Consistency

Due to the target population being industry experts and executives within the SA mining industry, the assumption is made that the dataset should be representative of respondents with experience of over 20 years. Data from respondents with less than 20 years' experience was however used in this project and therefore this section will test the significance of only using data from respondents with over 20 years' experience.

Respondents with more than 20 years' experience make up a sample size of 40 within the dataset. Using only this data, the median steady state of the system per transmitter node is compared to the full dataset, as described in section 4.4.3.

Figure **24** to Figure 28 shows that the Test Dataset of 40 respondents with over 20 years' experience is consistent with the Full Dataset used in this project. It can therefore be concluded that the full dataset is representative of experienced experts and executives in the SA mining industry.

Figure 24: Dataset Consistency: Resource Nationalism

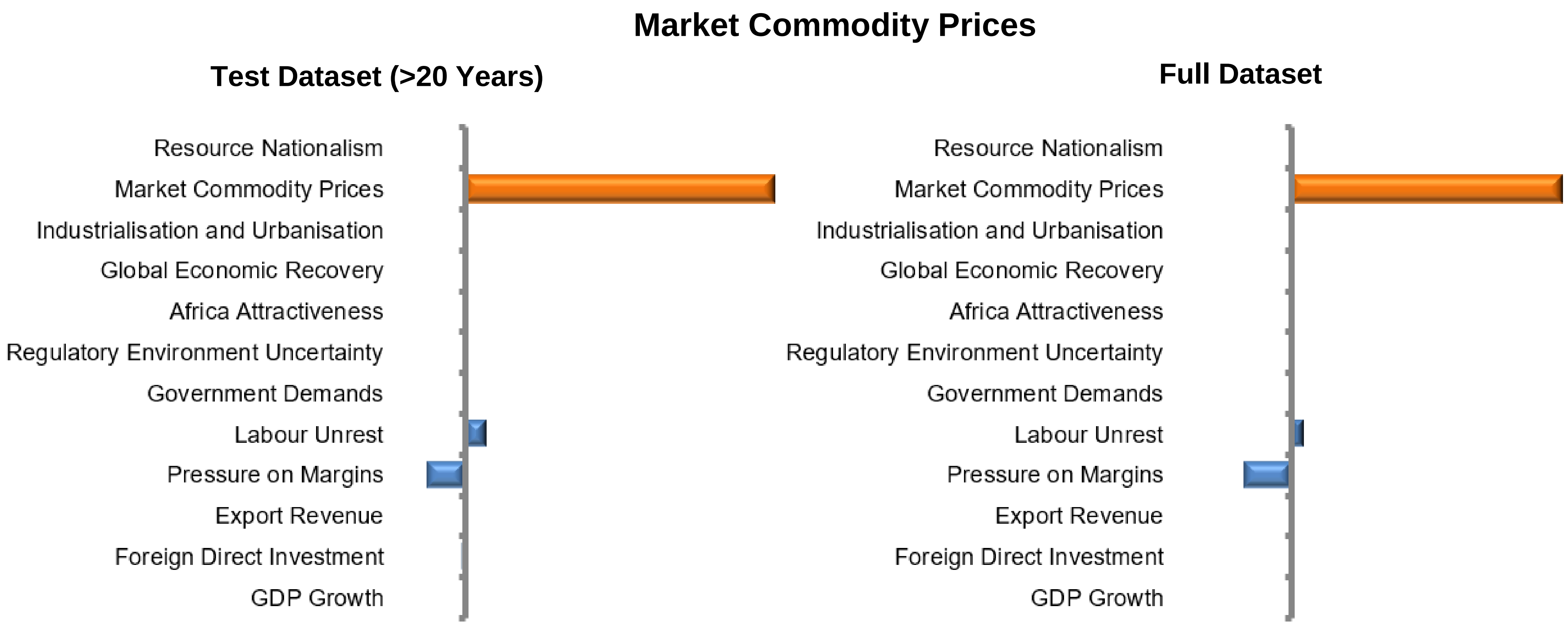

Figure 25: Dataset Consistency: Market Commodity Prices

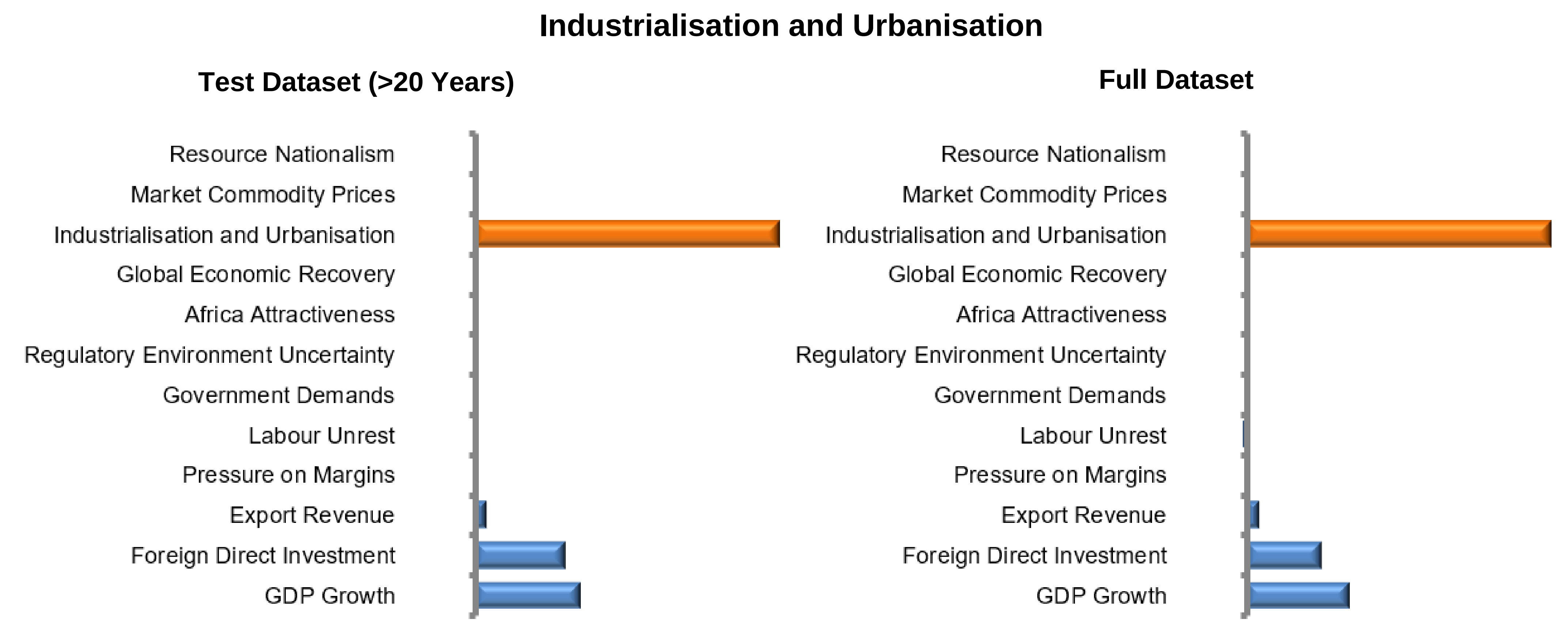

Figure 26: Dataset Consistency: Industrialisation and Urbanisation

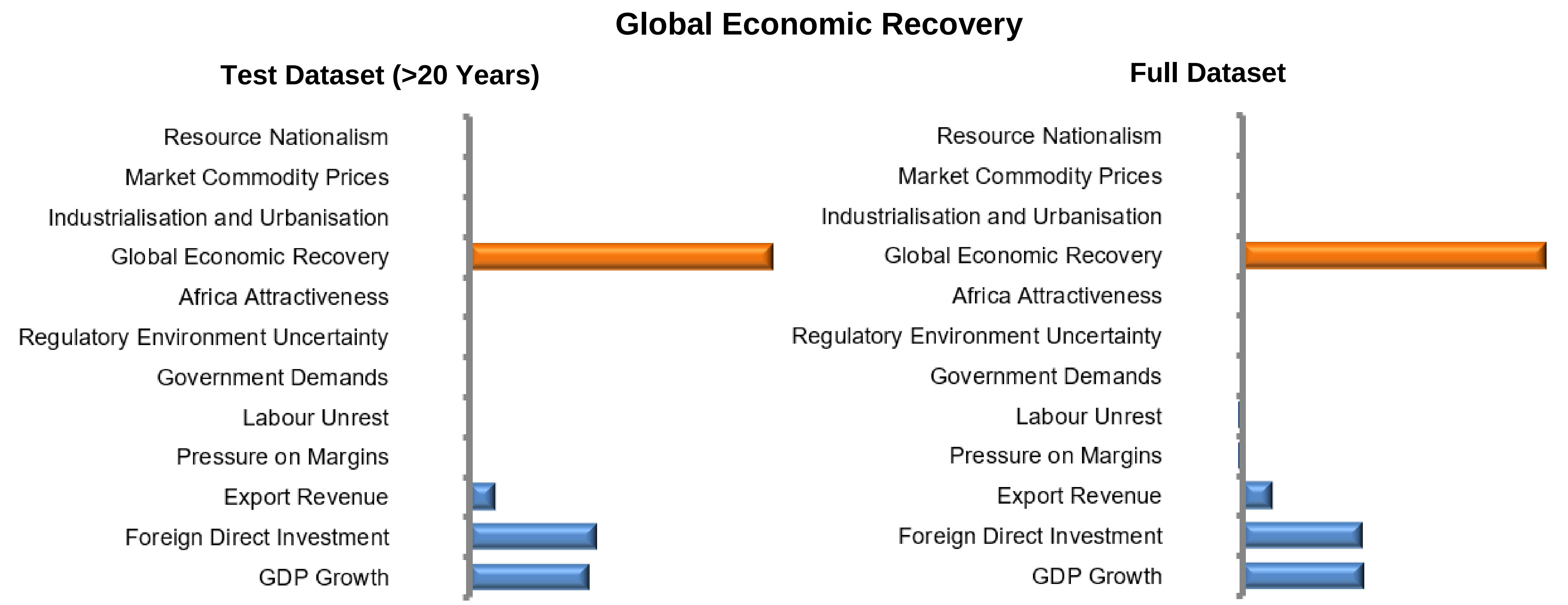

Figure 27: Dataset Consistency: Global Economic Recovery

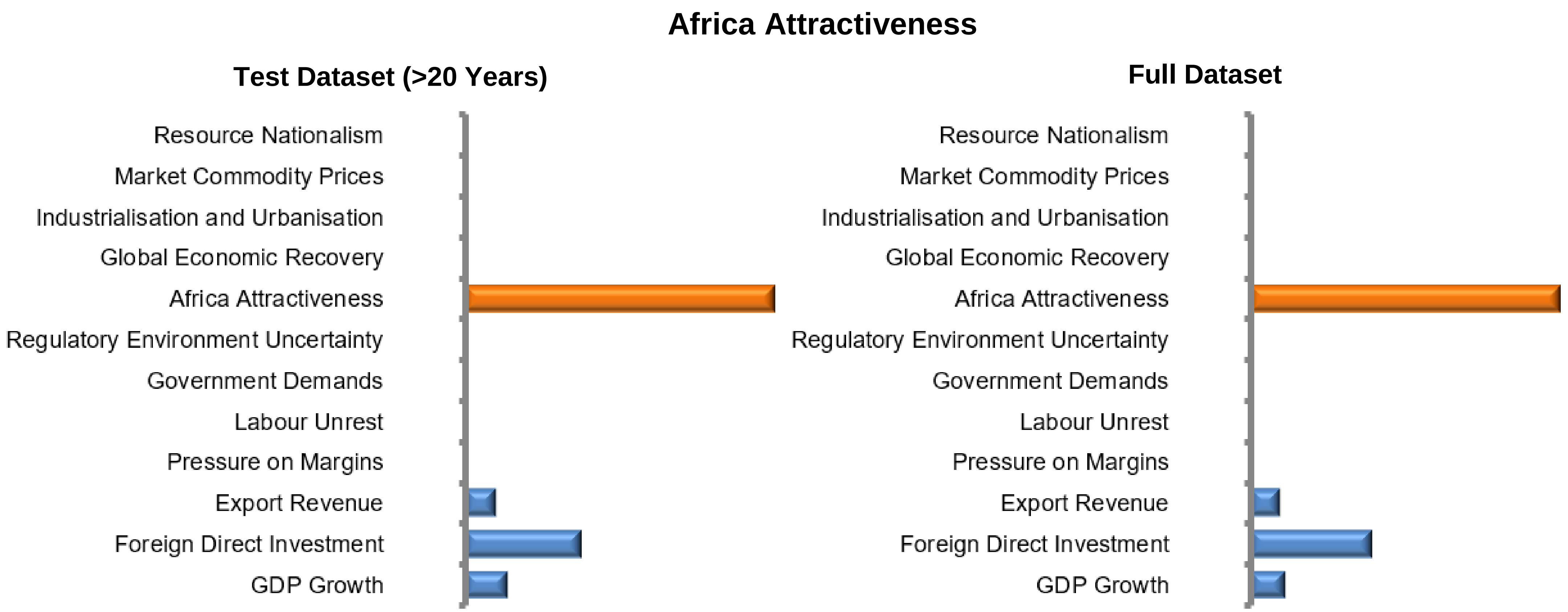

Figure 28: Dataset Consistency: Africa Attractiveness

4.5. Section Conclusion

A form of credibility to the model developed in this project is the 73 mining executives who completed the survey questionnaire. Having weighted and calibrated the model with the input from these influential persons in the SA mining industry, gives great confidence in the ability of the model to produce results that are realistic and have face validity.

This section has described how data was collected and analysed to assign weights, directions and validation to the FCM causal relationships. The rationale for using a survey questionnaire was stated along with the data collection sample size determination. Sensitivities were tested per individual transmitting node and the dataset was checked for consistency against a subset of experienced respondents.

5. MODEL VALIDATION

5.1. Section Introduction

The purpose of this section is to validate the FCM developed in this project by testing it against two scenarios with expected outcomes – Expected Worst Case and Expected Best Case. The model will be run with specific transmitter node state vectors for each scenario, as described in section 3.3.2 and analysed to determine whether there is congruence between the model results and the expected outcomes.

Once the model is validated, it may be used by mining executives to develop any other future scenarios that are plausible. Six alternative future scenarios were developed and analysed to demonstrate the model's agility and are shown in Appendix A – these scenarios include:

- Protectionist Commodity Rush into Africa
- World War III
- Non-Mining Sectors Thrive
- Protectionist Over Supply
- Wait for Africa to Bloom
- Stale Mate

5.2. Scenario 1: Expected Worst Case

5.2.1. Scenario Narrative

The year is 2038 and the SA government has seized all mining operations under a new Mining Nationalism Act. This is a global trend as other resource-endowed countries in Africa are also enforcing nationalism and protectionism, which is hampering economic growth and recovery since the global recession in 2008 (30 years ago) – in fact, the world is still reeling from a subsequent recession in 2025 when the cryptocurrency banking system was hacked and collapsed.

Commodity prices are falling in the midst of these structural trading barriers and due to a low global demand for resources. Industrialisation and urbanisation is reversing as people are moving away from cities to rural areas where they can afford to live. The global population of 8.2bn people has plateaued for the last ten years and coupled with the Fourth Industrial Revolution which has digitised the workplace, the global production capability and industrialisation has reduced.

Africa is not seen as the ‘last frontier’ for mining anymore as large-scale exploration projects during the ‘20s have yielded little promise of mines with high grades, easy conditions, or significant volumes. Investors have also shied away from Africa due to political and economic uncertainty, nationalism preventing corporate ownership and high barriers to trade.

This is regarded as the Expected Worst Case scenario. In this scenario it is expected that all KDFs contribute negatively to the system, hence severe industry loss and turmoil is envisioned.

5.2.2. Scenario Analysis

Figure 29 represents the Transmitter Nodes described in the scenario narrative. This unique assembly of state vector values (shown in Yellow colour) constitutes the Expected Worst Case scenario, as it is expected to yield a severely negative impact on the SA mining industry.

		Resource Nationalism	Market Commodity Prices	Industrialisation and Urbanisation	Global Economic Recovery	Africa Attractiveness
State Vectors	**1**	**1**	1	1	1	1
	0	0	0	0	0	**0**
	-1		**-1**	**-1**	**-1**	

Figure 29: Scenario 1 - State Vectors

Figure 30 and Figure 31 shows the results of this scenario. It is evident that Foreign Direct Investment and GDP Growth will reduce significantly. Export Revenue will suffer moderately, in part due to the trade-off between a weaker Rand that impacts exports positively and a low demand that impacts exports negatively. Regulatory Environment Uncertainty, Government Demands and

Labour Unrest are all on the rise in this scenario, which contributes negatively to the system.

Pressure on margins is a neutral but extremely erratic driver, as seen in Figure 31 and shows that there is potential to make profits if mines can be resourceful, but also to incur major losses if mines are not prudent.

Ultimately, these results show a severely negative position for the future of SA Mining and does indeed validate the model as an Expected Worst Case scenario.

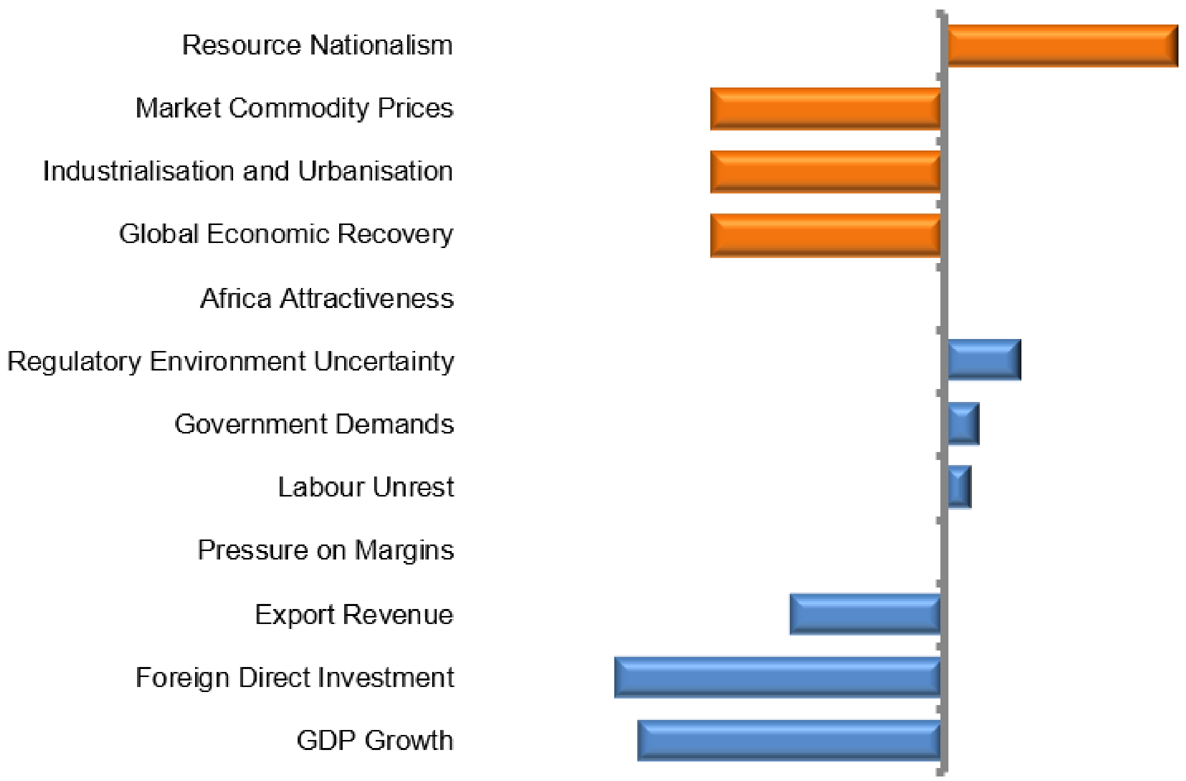

Figure 30: Scenario 1 - Results (Median)

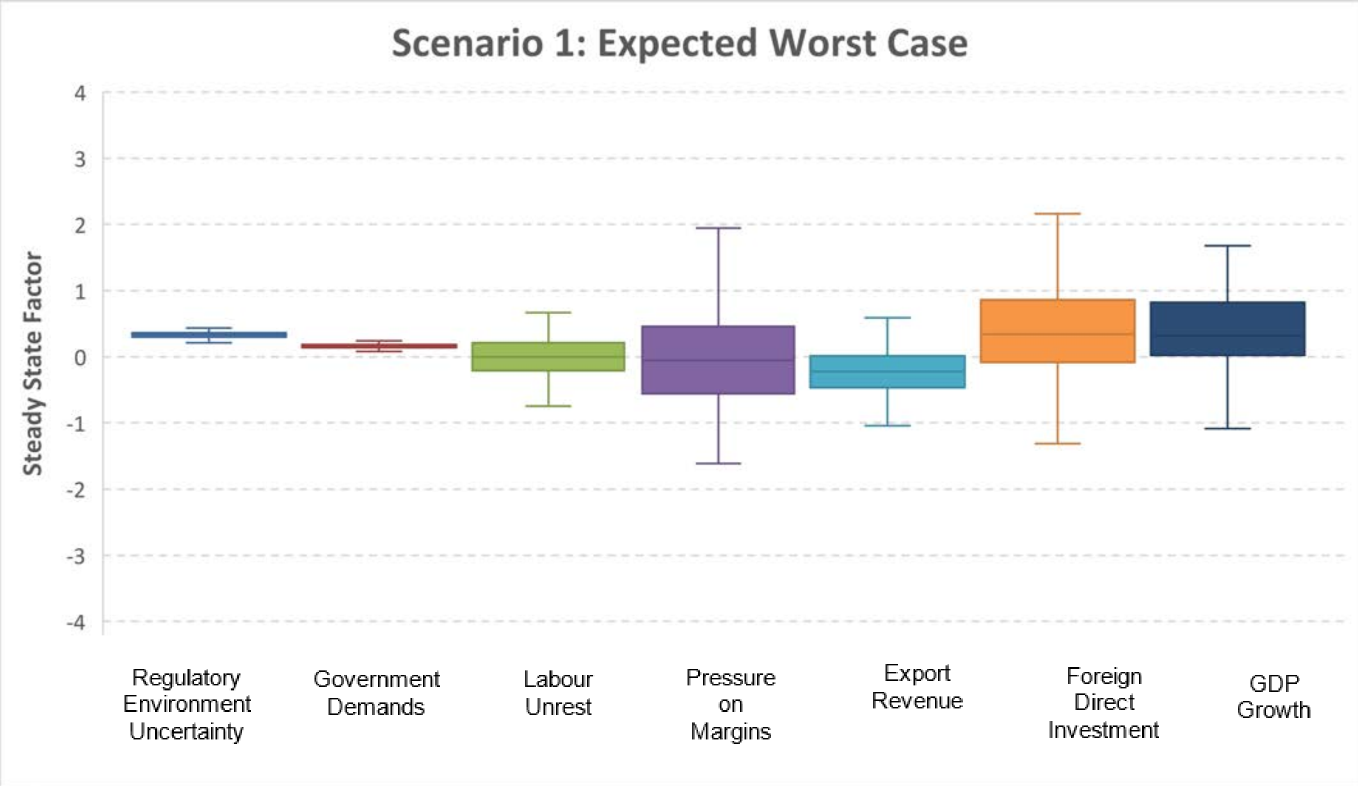

Figure 31: Scenario 1 - Results (Boxplot)

5.3. Scenario 2: Expected Best Case

5.3.1. Scenario Narrative

The year is 2038 and commodity prices are booming due to growing demand from China, India, Russia and South America. These developing countries have seen a surge in industrialisation and urbanisation as the Fourth Industrial Revolution has called for more knowledge workers in cities and larger expansions of the manufacturing sector due to highly automated work processes and robotics. The global population has been increasing exponentially and now hovers around 9.8bn people, showing no signs of slowing down.

Global free trade is enjoyed by mining companies and SA has instituted policy that supports mines to own, operate and exploit mining operations for the benefit of the company, surrounding communities and the economy.

The World Bank and International Monetary Fund (IMF) have built a sustainable global economic growth model that protects countries from economic lapse that could erode decades of progress, invests in underdeveloped countries and ensures basic needs are met. This growth model has been successful since the global economic recession in 2008 and has put the world on a fast track to economic recovery and growth for 30 years.

New resource discoveries in Africa during the 20's and 30's have shown great promise. Investors have been eager to enter into Africa, using SA as a gateway and the free trade agreements between SA and other African countries have paid large dividends in starting up new mines in Africa.

This is regarded as the Expected Best Case scenario. In this scenario it is expected that all KDFs contribute positively to the system, hence plentiful industry success and welfare is envisioned.

5.3.2. Scenario Analysis

Figure 32 represents the Transmitter Nodes described in the scenario narrative. This unique assembly of state vector values (shown in Yellow colour) constitutes the Expected Best Case scenario, as it is expected to yield a positive impact on the SA mining industry.

		Resource Nationalism	Market Commodity Prices	Industrialisation and Urbanisation	Global Economic Recovery	Africa Attractiveness
State Vectors	**1**	1	**1**	**1**	**1**	**1**
	0	**0**	0	0	0	0
	-1		-1	-1	-1	

Figure 32: Scenario 2 - State Vectors

Figure 33 and Figure 34 shows the results of this scenario. It is evident that Foreign Direct Investment and GDP Growth will increase significantly. Export Revenue will increase moderately, in part due to the trade-off between a stronger Rand that impacts exports negatively and a high demand that impacts exports positively. Regulatory Environment Uncertainty and Government Demands are neutral however Labour Unrest and Pressure on Margins have reduced moderately.

Ultimately, these results show an incredibly positive position for the future of SA Mining and does indeed validate the model as an Expected Best Case scenario.

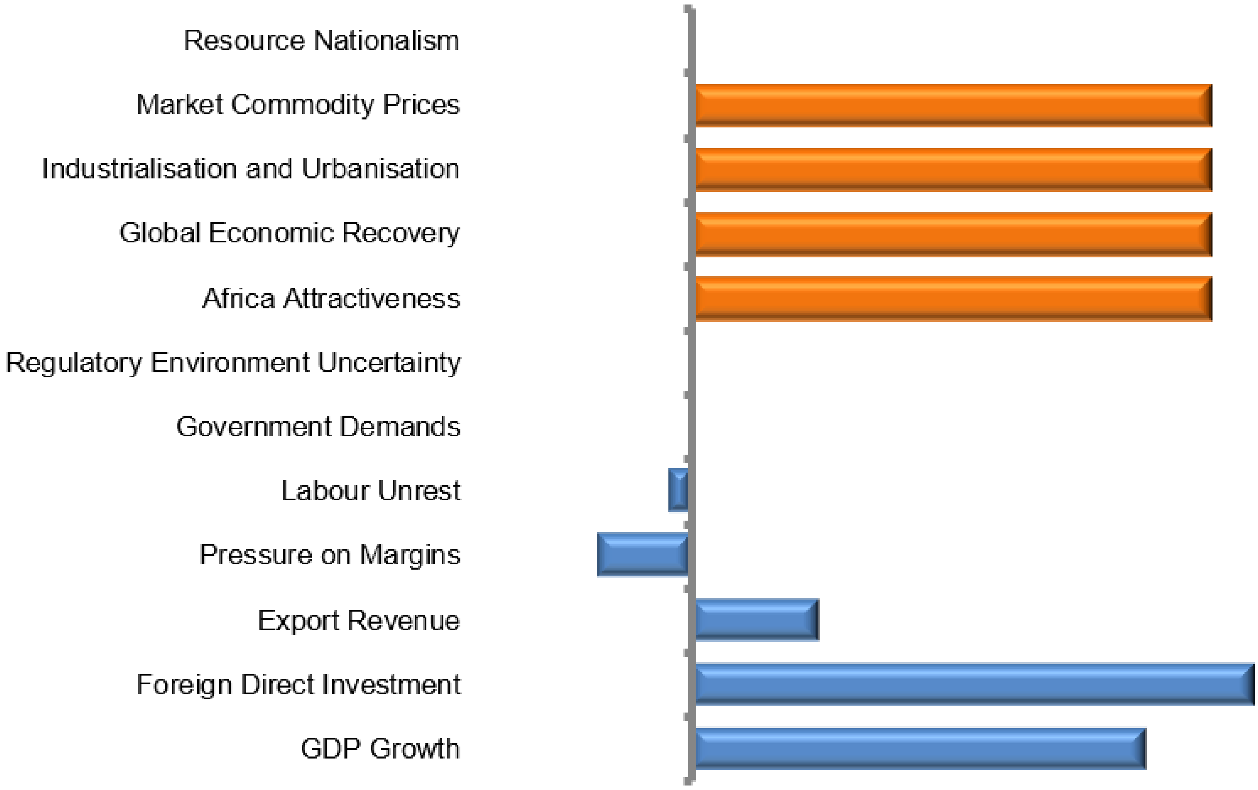

Figure 33: Scenario 2 - Results (Median)

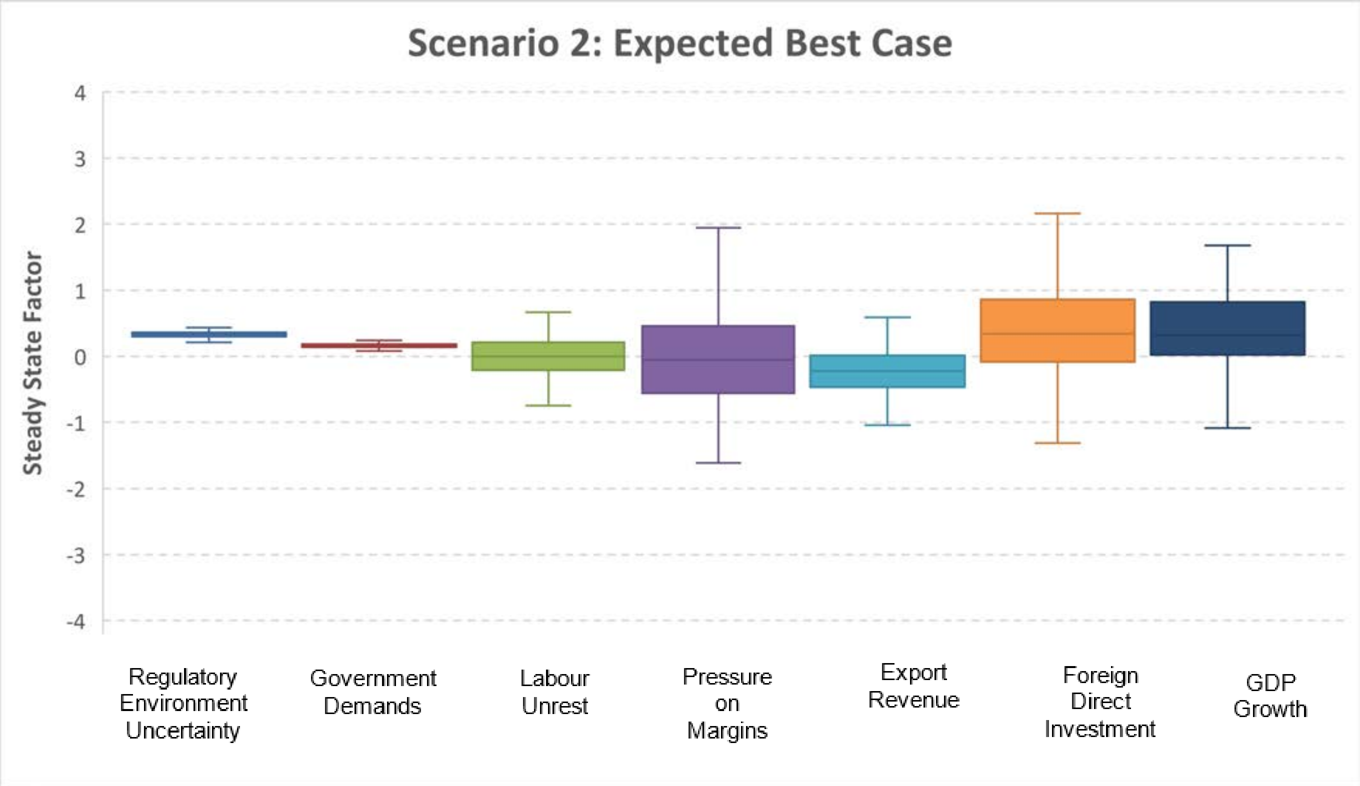

Figure 34: Scenario 2 - Results (Boxplot)

5.4. Section Conclusion

This section has validated the model developed in this project against two scenarios with expected outcomes – Expected Worst Case and Expected Best Case. In both scenarios, the model results showed strong congruence with the expected outcomes. Therefore, the model has been validated and can be used to develop any other plausible scenario within the SA mining context.

Mining executives now have a tool with which to model the future in a semi-quantitative manner. This technique assists mining executives to make informed, data-driven, decisions quickly and to gain a competitive advantage by preparing for the future.

6. CONCLUSION

6.1. Section Introduction

This section is aimed at concluding the project with a rationalisation of the problem statement fulfilment (section 6.2), recommendations for the target audience with practical considerations (section 6.3), proposed areas of further research (section 6.4) and consideration of unintended consequences of the project (section 6.5).

6.2. Problem Statement Fulfilment

The technique employed in this project fulfils the Main Problem Statement and its three Sub-Problems in section 1 as follows:

Main Problem: The FCM developed in section 3.5 encompasses a systemic view of the SA mining industry which may be used for scenario planning. This system model gives mining executives a competitive advantage to prepare for the future with multiple scenarios and ensure sustainability of their operations.

Sub-Problem 1: The data-driven approach to scenario planning, using the FCM developed in this project, is a semi-quantitative methodology. The subjectivity of experts and sole reliance on qualitative methods is therefore no longer necessary when applying the model developed in this project.

Sub-Problem 2: Using the agility of the model, mining executives are now able to make quicker decisions and get a better understanding of the impact of future scenarios on their strategies.

Sub-Problem 3: Using the model developed in this project, mining executives can develop future scenarios using more than two drivers. Five external drivers and seven internal drivers are included in the system model which caters for more depth of complexity which is inherent in the SA mining industry. Having weighted and calibrated the model using 73 survey responses from mining executives gives great credibility to the model and allows for this depth of complexity to be catered for.

6.3. Recommendations

The recommendations of the project are aimed at the target audience, which includes mining executives in the SA mining industry, mineral economists, strategic suppliers and customers of mines, resource policy makers and strategists. The implications and action plan of these recommendations are described in Appendix B.

6.3.1. Embedding of Data-Driven FCM for Scenario Planning

It is recommended that mining executives embed the process of scenario planning within their organisations for strategic foresight. Furthermore, the use of the FCM developed in this project will assist quicker and more data-driven decisions to be made and will ensure a systemic understanding of the complex system behaviour within the SA mining industry.

6.3.2. Adopt a Country Focus

The results of this project show that the successes of mines in SA are closely tied to the success of the economy, i.e. GDP, FDI, etc. It is therefore recommended that mining companies adopt a country focus instead of an industry focus to ensure that collaboration with SA government, labour and competitors is conducive to the success of these companies.

6.3.3. Strategic Foresight for Mining Feasibility Studies

Traditional mining feasibility studies don't always make use of strategic foresight techniques, and it is recommended that data-driven scenario planning, as performed in this project, is done as an input to mining feasibility studies. (Schoemaker, 1991) argues there is a link between project evaluation success and scenario planning. Once the multiple of plausible future scenarios is understood then the strategy and options available to the feasibility study gains context and is guided by a lucid systematic approach.

6.3.4. Key Recommendation

The field of strategic foresight and scenario planning is vast and even transpires the mining industry. The key recommendation from this project is that the technique of using a FCM and Adjacency matrix can be used in any industry, application, or future-oriented environment to better prepare for the future. It is recommended that this technique is used by any strategist or futurist to develop future scenarios in a data-driven manner and make decisions based on this semi-quantitative approach.

6.4. Areas of Further Research

This project was scoped to include 12 nodes and 35 specific causal relationships and weights within the SA mining industry. The following areas are proposed for further research:

1. **System Boundary Definition**: The FCM was developed for the SA Mining Industry and it is proposed that further research may follow the same approach to develop a FCM for another country, industry, or other system boundary.

2. **System Expansion**: The FCM was developed at a high level of detail and it is proposed that further research may include more nodes and links that expand the FCM to greater levels of detail. Also, the tailoring of the existing FCM is proposed for individual mines in SA to understand and compare the differences and impact of mining operations, commodities, geography, etc.

3. **Automation**: The FCM was developed from research and a survey questionnaire to assign link weights and it is envisioned that the FCM may be developed further to greater levels of detail (as described in no.2) where

some nodes may be connected to live sources of data. Once nodes are updated from live data sources, machine learning and artificial intelligence (AI) may be applied to adjust link weights, assign different links and even adjust nodes and the system model structure. This will then become a fully quantitative tool for scenario planning that updates automatically and acts as a “black box” to the user.

4. **Value Measurement**: Further research may apply the FCM developed in this project, or a variant with the same approach, to a specific context, i.e. develop scenarios for a mining client. Once the scenarios have been defined, a method of measuring value from the process may be proposed from research. This value measurement will be based on initial scenarios developed and how it has impacted the performance of the recipient to create or destroy value.

6.5. Consideration of Unintended Consequences

A consideration of the unintended consequences from the project reveals the following:

1. **Detrimental Strategic Decisions:** It is acknowledged that the FCM developed in this project may not be fully suited for specific applications, such as investing, mining operations, etc. and therefore if stakeholders were to make decisions based on the results of this project is may lead to unintended negative consequences. It is advised that stakeholders tailor the FCM to fit their unique purpose and apply face validity and sound judgment when making decisions based on the model.

2. **The “Accurate Scenario Flaw:** It is considered that stakeholders may misinterpret the plausible scenarios put forward by this project as being an accurate forecast. This is an incorrect view as scenarios are not meant to portray the accurate truth of the future, but rather are meant to stretch the mental models of stakeholders to consider extreme alternatives of the future, as described in section 2.2.3.

3. **Static System Model:** It is acknowledged that the definition of the FCM system model is not static and may change over time. Stakeholders are therefore advised to keep the model relevant and updated with new research.

4. **Fuzzy Logic Misinterpretation:** It is acknowledged that the model results are not "exact" and cannot be interpreted as discrete or precise values, due to the nature of fuzzy logic and systems thinking. The results should rather be interpreted relative to other results in a broad sense.

5. **Qualitative Bias:** It is acknowledged that the setup of a scenario may not be standardised and can therefore influence the result. As the modeller will insert the transmitter node state vectors and may define these values differently from the next modeller there is a bias in defining the unique mix of external values that make up a scenario and even the narrative of the scenario – it is therefore advised that stakeholders account for this bias and agree on methods for defining scenario inputs.

6. **Surprise Scenarios:** The nature of scenario planning is that the stakeholders should be 'surprised' by scenarios that stretch conventional mental models. It is therefore expected that unintentional 'surprises' will emerge from the application of this project and challenge the way mining executives in SA view the future.

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