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CENTRE FOR TRADE POLICY AND DEVELOPMENT

Strategy for growing the Zambian Manganese mining sector through the lens of Artisanal and Small-scale mining

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JOINT COUNTRY PROGRAMME **ZAMBIA**

EXECUTIVE SUMMARY

The manganese industry is an essential part of Zambia's mining sector. It represents a potential platform to catalyse economic development and poverty reduction. Due to its unique chemical properties, manganese has found wide applications in battery cathodes, steel manufacturing, alloying of copper and aluminium, colourant in glass, and use as a micronutrient element in fertilisers and animal feeds. These industrial uses advance a narrative that manganese is a metal that will have increased demand in the foreseeable future. This further pinpoints the need for the Zambian Government to strategically reposition itself to harness and exploit the mineral for the benefit of the citizenry. Although Zambia is richly endowed with a vast amount of manganese reserves it has failed to capitalise on this and reach higher levels of economic growth. This is partly due to the reason that the sector is underdeveloped because of the many challenges it continues to face. The Zambian manganese mining sector is heavily dominated by Artisanal and Small-scale Miners (ASM). Therefore, a strategy of growing the sector will need to be deployed through the lens of these miners.

This study had the objective of devising a strategy for growing the Zambian Artisanal and Small-scale Manganese Mining (ASMM) sector to induce economic development and poverty reduction. This study was conducted in three districts, namely, Mkushi, Serenje, and Mansa. Twenty-four challenges impeding the growth of the ASMM sector were identified in these areas. The intensities of these challenges in the three study areas were determined through a questionnaire survey having intensity scores of 5, 4, 3, 2, and 1 which respectively denote very high, high, medium, and low intensities. These were later averaged to determine the aggregate ratings in all three areas.

From the results, occupational, health, and safety challenge had the highest intensity and had a classification of very high. Thirteen challenges were classified as being high, namely, lack of geological information, use of inefficient mining methods, poor mining facilities, limited supply of electrical power to mine sites, lack of robust mine planning, low manganese prices, high tax rates, high operating cost, lack of fiscal incentives to support the growth of the sector, lack of startup and working capital, lack of technical and financial knowledge, and presence of illegal miners. Since taxation is a quantitative variable it was assessed by generating technical-financial spreadsheet models of four ASM operations. Results showed that the current taxation regime exerts a high fiscal burden on the four projects with average effective tax rate and marginal effective tax rates exceeding 39%, and 41%, respectively. This collaborated with the survey results indicating that the intensity of this challenge is high in all three areas. Eight challenges were classified to have a medium intensity, namely, lack of mining equipment to exploit orebodies, lack of skilled labour force, use of inefficient processing techniques, weak regulations and law, lack of institutional capacity, bureaucracy in obtaining mining licenses, and lack of implementation of regulations. Lastly, two challenges were classified as being low, namely, lack of a readily available lucrative market and lack of a marketing strategy.

After determining the intensity ratings of the challenges, they were then classified into causal and effect groups. The number of causal and effect challenges were 9, and 15, respectively. The identified causal challenges were lack of geological information, lack of skilled labour force, bureaucracy in obtaining mining

license, lack of fiscal incentives to support the growth of the sector, weak regulations and laws, high tax rates, lack of startup capital, lack of technical and financial knowledge, and lack of institutional capacity. The other remaining challenges were classified as effect challenges. It is important to stress the fact that causal challenges are the primary factors that lead to effect challenges. Therefore, the government must be overly obsessed with resolving them through strategic policy response.

Perceptual strategies for growing the ASMM sector were obtained through high-level stakeholder consultations. Three main issues emanated from these consultations, namely, reduction of the tax rate in the manganese mining sector, formalization of the sector, and rendering of technical and financial assistance to the miners. Based on the strategic policy responses to the identified causal challenges and stakeholder consultations, a strategy for growing the Zambian manganese mining sector through the lens of ASM was proposed. The strategy is a five-step process that involves, the formalisation of the ASMM sector by primarily addressing causal challenges; partnering government, local and foreign investors with artisanal and small-scale miners; setting up mineral processing facilities; creating market hubs, and generation of a conducive business environment through policy to support downstream manufacturing plants. It is important to note that feeding manganese to downstream industries such as steel and battery manufacturing will culminate in poverty reduction and above all, it will induce macroeconomic growth because of increased foreign exchange, export earnings, employment, and domestic revenue generation through taxation and other fiscal instruments. It is important to mention that the steps of the proposed strategy can be undertaken solely or simultaneously depending on the circumstances at play.

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FOREWORD

I am delighted that we now have a detailed research report on manganese that can be referred to by different stakeholders in the mining sector. This research piece provides empirical evidence that will help in growing the sector. A preliminary review shows that there is limited literature on manganese mining in Zambia. This triggered interest from the Centre for Trade Policy and Development (CTPD) supported by the Norwegian Church Aid (NCA) to undertake an in-depth analysis of the manganese mining sector to document evidence of this strategic mineral. This study is finalized at an opportune time when the country has signed an MoU with the Democratic Republic of the Congo (DRC) to mutually invest in developing the battery value chain. I hope this mineral can be used as a strategic agent in realizing a fully vertically integrated battery manufacturing process in Zambia and the DRC.

I am glad that we have gotten to the end process and now have a report on the detailed strategy of how to grow the manganese sector through the lens of Artisanal and Small-scale Mining (ASM). Certainly, this piece is not exhaustive but surely presents itself as a strong reference point for subsequent studies on the manganese sector in the future.

To the policymakers, particularly, the Government of the Republic of Zambia (GRZ), this report contains critical information and recommendations that can help grow this infant sector. We are grateful for your technical support in completing this study. Particularly, I want to show great appreciation to the Ministry of Mines and Minerals Development for its contribution through interviews and reviewing the report when it was still in draft form. Additionally, we say many thanks for providing technical assistance during field visits to remote manganese ASM sites in Mkushi, Serenje, and Mansa.

Mr. Isaac Mwaipopo
Executive Director
Centre for Trade Policy & Development

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The Centre for Trade Policy and Development (CTPD) would like to extend sincere gratitude to the Norwegian Church Aid (NCA) for funding this study without whose support this report could not have been actualised. CTPD further extends its appreciation to various institutions and individuals that played a key role in shaping the outcomes of this study, key among these include the Ministry of Mines and Minerals Development (MMMD), Zambia Chamber of Mines, Small-scale mining associations, Zambia Consolidated Copper Mining Investment Holdings (ZCCM-IH), and the Directors and Managers of Artisanal and Small-scale Manganese Mining (ASMM) projects in Serenje, Mansa and Mkushi. Last, but not least CTPD extends its appreciation to the miners at sites who provided valuable information for the study.

CTPD explicitly thanks Mr. Isaiah Mbewe, and Mr. Boyd Muleya for the immense effort expended in the data collection process. Special thanks also go to the reviewers for their constructive comments and suggestions. Last, but not least sincere gratitude is extended to the CTPD media team for ensuring that a final version of this report is actualised.

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LIST OF ACRONYMS

AETR	Average Effective Tax Rate
AMV	Africa Mining Vision
ASMM	Artisanal and Small-scale Manganese Mining
ASM	Artisanal and Small-scale Mining
CBU	Copperbelt University
CIT	Corporate Income Tax
CTPD	Centre for Trade Policy and Development
DEMATEL	Decision Making Technique Evaluation Laboratory
GDP	Gross Domestic Product
GSD	Geological Survey Department
JVP	Joint Venture Partnership
METR	Marginal Effective Tax Rate
MMMD	Ministry of Mines and Minerals Development
MPRDA	Minerals Petroleum Resources Development Act
MSMED	Ministry of Small, Medium, Enterprise Development
PML	Primary Mining Licenses
UNZA	University of Zambia
USGS	United States Geological Survey
ZDA	Zambia Development Agency
ZCCM-IH	Zambia Consolidated Copper Mining Investment Holding

1.0 INTRODUCTION

1.1 Background

In the last 100 years, the mining sector has continued to be the backbone of Zambia's economy. At present, the sector contributes about 14% to Gross Domestic Product (GDP), over 70% of export earnings, and between 26-30% to domestic revenue generation (Banda, 2019). The sector also contributes over 70,000 direct jobs (ZEITI, 2020). However, it is worth noting that over these years the country has been heavily reliant on large-scale mining at the neglect of the Artisanal and Small-scale Mining (ASM) sector. The latter presents itself as a conduit for initiating social-economic development. It is for this reason that energies must be channeled into growing this infant sector. This can only be realized by addressing the many challenges that the sector continues to face.

ASM, unlike large-scale mining, is dominated by local citizens. This local drive can be attributed to low capital intensity, low barriers to entry, and high-income generation potential (Banda, 2021). Due to this, the sector has seen increased participation of youths, women, and children. ASM can involve people working as individuals, in cooperatives, or in other forms of legal associations and enterprises. Although ASM is attributed to poverty-stricken individuals it is important to note that literate, and educated people are also participating to have a share of the mining cake. This participation also extends to some political players who are involved in the supply chains as traders. Due to their affluence, these individuals can sometimes exert their influence to become dominant saboteurs of ASM by fueling illegality. It is worth mentioning that a larger part of ASM activities is illegal or informal. This has inhibited the sector's real contribution to economic development.

Although many countries recognize the ASM sector`s contributions, most have been reluctant to convert the sector into a tool of national development through policy response. This can partly be attributed to the difficulty of integrating the sector into the formal economy. The sector's negative challenges including prostitution, crime, human rights abuse, child labour, and problems with occupational health and safety sometimes make it difficult for governments to advance a convincing narrative to their citizens for them to provide technical and financial support to ASM. In most countries, citizens view the ASM sector as a nuisance with little or no benefit and largely proliferating the aforementioned negative challenges. Additionally, Governments of Sub-Saharan Africa have limited operational budgets to support the mining sector. This coupled with the huge revenues derived from large-scale mining has resulted in the sector being neglected in the doldrums with much attention being diverted to the former. However, this should not be the case because the ASM sector provides a potential platform for alleviating poverty and inducing economic growth.

ASM in Zambia has been mainly focused on Gemstone mining (Siwale and Siwale, 2017). However, it is important to stress that manganese presents itself as an avenue for growth. Part of the reason is that this mineral can be interlinked with the wider economy to induce economic development, poverty reduction and subsequently reduce the income inequality gap between the rich and the poor. In the past two years,

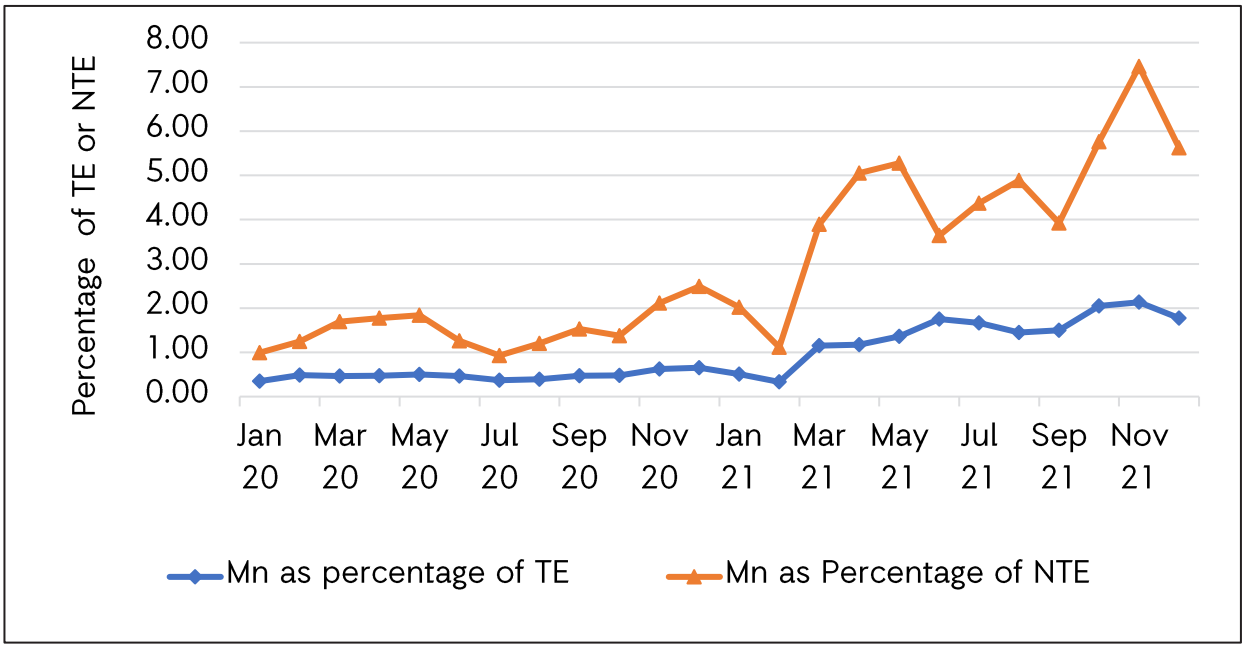

Figure 1 Manganese as a percentage of Total Exports (TE) and Non-Traditional Exports (NTE)

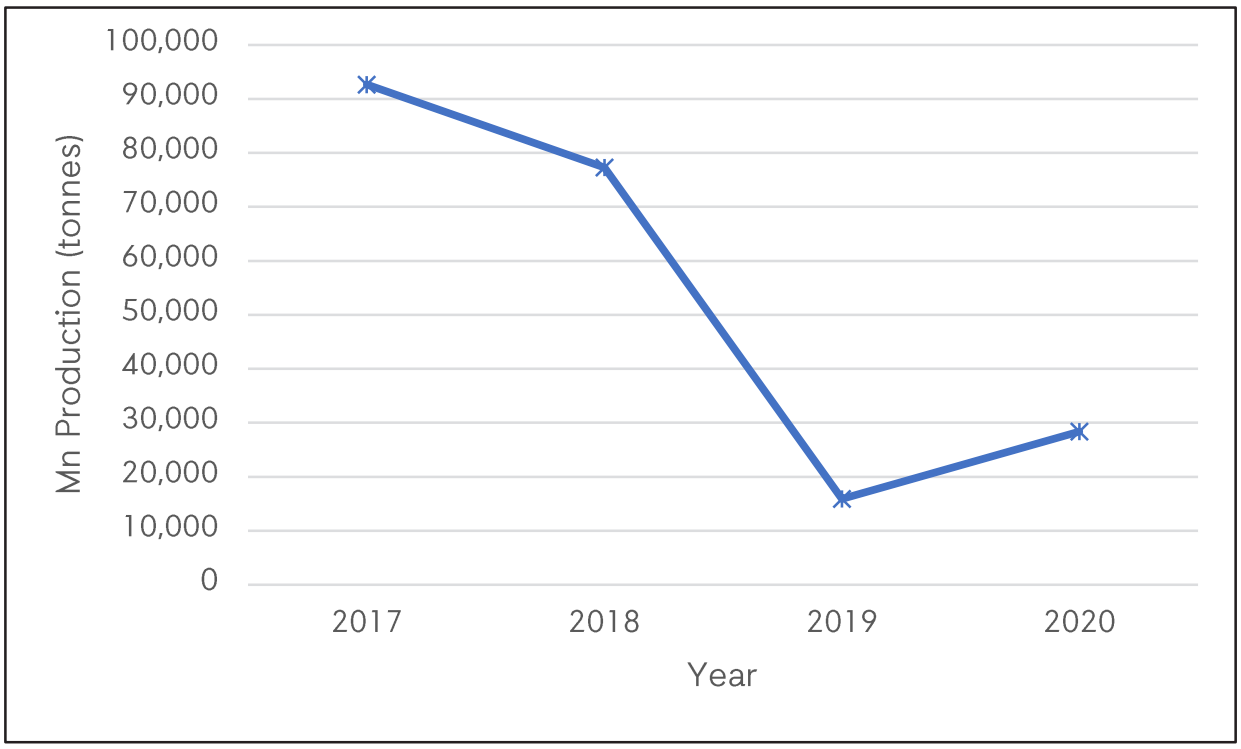

Figure 2 Manganese production (2017-2020)

It is important to stress the fact that the sector is still in its infant stage because of the many challenges it continues to face. This can partly be attributed to the fact that the sector is dominated by ASM players. Therefore, solutions that aim at growing the sector must be deployed through the lens of ASM. This being so, this study focuses on devising a strategy for growing the manganese sector through ASM players.

1.2 Research Objectives

The main objective of this study is to devise a strategy for growing the Zambian Artisanal and Small-scale Manganese Mining (ASMM) sector to induce economic development and poverty reduction. The specific objectives include:

(i) To identify and rank the causal and effect challenges that impede the economic growth of the ASMM sector;

(ii) To craft strategic policy responses that aim to mitigate the impact of causal challenges on the ASMM sector;

(iii) To undertake high-level stakeholder consultations to tease out the perceptual strategies for growing the ASMM sector; and

(iv) To formulate a proposed strategy for growing the sector.

1.3 Significance of the study

This study will feed into the process of formulating robust policies that will enhance the growth of the ASMM sector in Zambia. Additionally, the study will serve as an important advocacy tool for promoting positive policy change. This will ensure that members in communities hosting manganese mineral resources attain maximal benefit subsequently leading to poverty reduction and national economic development. Being the first study to dichotomize challenges in Zambia's ASMM sector into cause-and-effect groups, it presents a road map that can be undertaken by the government to resolve sector causal challenges that can subsequently grow the sector thus addressing poverty reduction and inducing macroeconomic growth.

1.4 Layout of the report

This report is organized as follows. The first part elaborates on the background of the study and its objectives. The second part gives a brief overview of the manganese value chain. The third section explicates the Africa Mining Vision in the context of ASM. Additionally, ASM literature from South Africa and Tanzania was reviewed for peer learning. The fourth section explains the research methodology that has been employed to realize the objectives of this study. The fifth section elaborates on the data collected from the study areas. The proceeding section analyses the data collected and discusses the results. The last section gives concluding remarks and makes relevant policy recommendations to the government.

2.0 THE MANGANESE VALUE CHAIN

Manganese is a common ferrous metal with an atomic weight of 25 and has the chemical symbol Mn. It constitutes roughly 0.1 percent of the earth's crust making it the 12th most abundant element (Cannon, 2014). Manganese is naturally found in a variety of minerals, but never on its own. According to the Mines and Minerals Development Act No.11 of 2015, manganese is classified as a base metal. According to the Act, a base metal Is a mineral that is common and chemically active. Other physical properties of manganese are its pinkish-gray colour, high brittleness, and hardness. Additionally, it is easily oxidized, dissolves in dilute acids, is reactive when pure, reacts with water, and burns in oxygen when in powder form.

Manganese is extracted from manganese ore in the form of manganese oxide (also known as pyrolusite) or iron ores. Therefore, manganese mining is subsumed under iron mining (Gajigo et al., 2011). Apart from the ores being extracted from the same geographical locations, there are related due to their complementarity in steel production. It is for this reason that the three industries – manganese, iron, and steel are intricately linked (see Figure 3). Most manganese ores are extensive layers of manganese-rich sedimentary rocks. Land-based resources are sporadically distributed. South Africa hosts about 80 percent of the world's manganese reserves (Zyl et al., 2016). Other countries with a vast amount of reserves are Australia, China, Gabon, Brazil, Ukraine, and India. An additional potential source of manganese is the vast layer of ferromanganese nodules that cover the floors of oceans. According to Cannon (2014), these potato-sized nodules are currently the target of exploration and research for thirteen organizations aimed at economic development mostly focused on the equatorial Pacific Ocean. Once these nodules are proved viable to mine, they will serve as a great source of manganese in the foreseeable future. Iron ore, on the other hand, is mined across different countries globally. The largest producers are China, Australia, Brazil, India, and Russia. These countries including Kazakhstan hold the largest reserves. When it comes to steel production, China is the largest producer accounting for over 50 percent of global production. According to the World Steel Association (2021), China produced 83.2 Mt in August 2021, down 13.2% in August 2020. India produced 9.9 Mt, up 8.2%. Japan produced 7.9 Mt, up 22.9%. The United States produced 7.5 Mt, up 26.8%. Russia is estimated to have produced 6.3 Mt, up 4.4%. South Korea is estimated to have produced 6.1 Mt, up 6.2%. Germany is estimated to have produced 3.0 Mt, up 6.7%. Turkey produced 3.5 Mt, up 7.1%. Brazil produced 3.1 Mt, up 14.1%. Iran is estimated to have produced 2.5 Mt, up 8.7%. World crude steel production for 64 countries reporting to the World Steel Association was 156.8 million tonnes (Mt) in August 2021, a 1.4% decrease compared to August 2020 (World Steel Association, 2021).

The outlook of the steel industry hinges on the manganese sector for the following four reasons:

(i) Manganese is primarily used in steel manufacturing, which accounts for approximately 90 % of the total manganese demand (Gajigo et al., 2011).

(ii) It is used as an alloying material

(iii) There are no suitable alternatives for manganese in steel production (Gajiogo et al., 2011; Olsen et al., 2007)

(iv) Vertical integration in the global manganese value chain (which means leading steel companies are to some degree involved in manganese production). (Bonga 2008; Gajiogo et al., 2011).

It is important to mention that Manganese has unique chemical properties that make it ideal in the manufacturing process of ferroalloys (i.e., ferromanganese and silicomanganese), and subsequently steel. Although a larger feed in steel production emanates from iron, manganese is just as critical. The use of manganese in steel production is twofold. Firstly, it imparts strength and removes the brittleness of the metal. Secondly, it is used in the refinement of iron ore as it removes sulfur and oxygen impurities. According to the United States Geological Survey (USGS) (2009), the amount of manganese ore used per ton of steel is rather small ranging from 6 to 9 kilograms. Apart from steel manufacturing, manganese is also used as an alloy with metals such as copper and aluminum. When used with aluminum it adds to corrosion resistance. It is for this reason that most beverage cans consist of about 1.5% manganese (USGS, 2009). Looking at the different and many industrial uses of manganese, it can be safely concluded that it is a critical element in our modern societies. The infrastructure that we and will continue to see today and in the future can and will be traced back to this important mineral. Therefore, countries richly endowed with this mineral resource, including Zambia need to move aggressively to transform it into a strategic tool for reducing poverty and proliferating economic development.

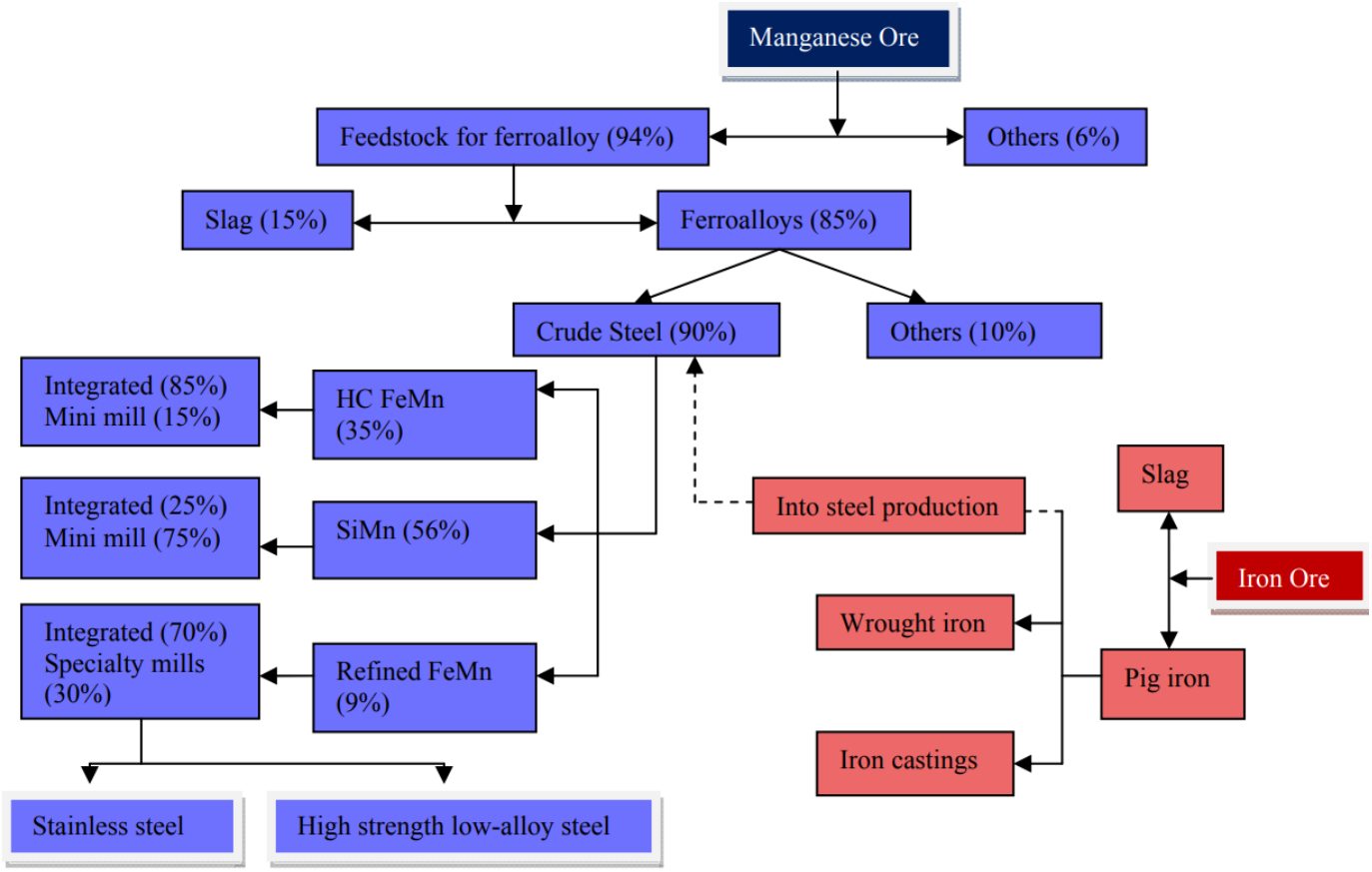

Figure 3 Manganese ore industry structure (Gajigo et al, 2011)

3.0 AFRICA MINING VISION (AMV) AND PEER LEARNING

In this Section, the sector is contextualized under the aspiration of the Africa Mining Vision (AMV). Secondly, literature in other countries is reviewed to illuminate success and failure stories in managing the ASM sector.

3.1 AMV as a guideline for ASM development

The AMV is a continental policy framework that aims at promoting the transparent, equitable, and optimal exploitation of mineral resources to underpin sustainable and social-economic development in Africa (Banda, 2019). According to the United Nations Economic Commission for Africa (2014), the vision is centered on seven critical points:

(i) Fiscal regime and revenue management;
(ii) Geological and mineral information systems;
(iii) Building human and institutional capacity;
(iv) Artisanal and small-scale mining;
(v) Mineral sector governance;
(vi) Linkages, investment, and diversification; and
(vii) Environmental and social risk.

The AMV does recognize the need to harness the potential of ASM to stimulate local/national entrepreneurship, improve livelihoods and advance integrated rural social and economic development. Additionally, the AMV outlines that the ASM sector must promote linkages between research development and innovation. It must also link to other economic and social sectors, through knowledge creation, and greater domestic financing (United Nations Economic Commission for Africa, 2014).

3.2 Experiences of the ASM sector in other countries

This section sheds light on ASM experiences in other countries, particularly, South Africa and Tanzania. The literature survey aims at uncovering what Zambia can learn from others in terms of the challenges faced, and effective and ineffective solutions that have been deployed to grow the sector over time. This feeds into the process of mapping out strategies that can grow the ASMM sector in Zambia.

3.1.1 South Africa

Most of the ASM literature on South Africa has been drawn from Ledwaba and Nhlengetwa (2016). It is important to appreciate that the mining legislation in South Africa has evolved to make the mineral sector more accessible to the previously disadvantaged South Africans. The recognition of the ASM sub-sector is one way to remedy the past injustices of the apartheid regime. In the last two decades of promoting the ASM sector, South Africa has managed to do several things right. Notwithstanding this, it has also faced several challenges. The acknowledgment of the ASM sector in the main legislative framework is one step in the right direction. However, the legislation does not differentiate between large and small-scale players. To this extent, ASM is perceived to be unfairly treated thus exacerbating informality. Secondly, introducing a "special permit" as a way of accommodating small-scale players is a good initiative. However, the requirements of the Minerals Petroleum Resources Development Act (MPRDA) require a costly feasibility study to be undertaken. This requires hiring consultants with the requisite skills set to technically and financially evaluate a project for viability. in addition to this, a capital intense environmental impact assessment has to be completed.

The administrative processes of obtaining the permits are deemed to be complex because they require the use of the internet and computer which most ASM aspirants are not conversant with. The provisions of the permits present barriers even to those who manage to get access to them. For instance, the size and duration of the permits potentially limit the growth of the sub-sector. Additionally, the ASM operators find it difficult to secure funding from money lending institutions because the payback period is too long. They also fail to secure long-term contracts because the productive life of their mining areas is short. Another critical issue that has prevented the growth of the sector is the lack of sufficient institutional capacity to monitor and evaluate ASM activities. As a concluding remark, the policy framework is not working because it does not speak to the needs of the ASM sub-sector. This is partly attributed to the fact that South Africa has, over the years, used an umbrella approach in addressing ASM-related issues.

3.1.2 Tanzania

Most of the Tanzanian ASM literature covered in this section has been drawn from Schonevald et al. (2017). In Tanzania's ASM sector, access to finance and modern technology is limited. Additionally, linkages to LSM are weak with most operators relying on rudimentary and unsustainable production practices, Due to this, they are unable to develop the necessary mining infrastructure, and are confronted by poor economic efficiency and recovery rates. As a result, the ASM sector is yet to realise its full growth potential. Tanzania does not have a well-developed medium-scale sector to help bridge the gap between LSM and ASM. However, in recent years Tanzania has seen an influx of foreign-owned mining companies that are directly engaging with ASM. The foreign investors act like sponsors of mining operations on Primary Mining Licenses (PML) (an ASM license reserved for Tanzanian citizens). The primary benefit of Investor-PML partnerships is that they lead to the development of dormant mines. Additionally, communities benefit from investor corporate social responsibility. Additionally, these partnerships have resulted in better occupational safety, health, and environmental performance because of the advanced technology employed. Under the investor-PML partnership, a formal structure is adopted where miners receive a fixed salary. While this guarantees job security, miners do not participate in the profit potential of the mine. Another pitfall is that they have not propelled skills development. This is mainly attributed to the fact that vacant positions accessible to locals are of menial type whilst most of the technical positions are given to expatriates. This limits the transfer of technical skills from the investors to the locals.

4.0 RESEARCH METHODOLOGY

4.1 Introduction

This section discusses the research design focusing on the quantitative and qualitative methods utilized to collect and analyse the data. It focuses on diagnosing the challenges of the ASMM sector by pinpointing solutions aimed at growing it to induce poverty reduction and economic development. To effectively attain this, the data collection process was sectioned into four main components, namely, desktop review, key informant interviews, high-level stakeholders' consultations, and a challenge questionnaire survey.

4.2 Data Collection process

This section explicates the data collection techniques that were used to gather data for the research study. These comprise desktop reviews, high-level stakeholder consultations, key informant interviews, and a challenge questionnaire survey.

4.2.1 Desktop review

A desktop review was undertaken to shape the design of the primary data collection process by generating relevant research variables. Through the desktop review, possible challenges impeding the growth of the ASMM sector were preliminary identified. Data for desktop review was obtained from both published and unpublished sources.

4.2.2 Key informant interviews

Twenty-five key informant interviews were conducted with artisanal and small-scale miners, machine operators, and mine equipment owners. The purpose of the key informant interviews was to uncover additional challenges of the ASMM sector at mine sites not identified during the desktop review.

4.2.3 High-level stakeholder consultations

Eight high-level stakeholder consultative meetings were undertaken to identify challenges and tease out possible growth strategies for

the ASMM sector. Specifically, meetings were held with the Zambia Chamber of Mines, Ministry of Mines and Minerals Development (MMMD), Academia, small-scale mining associations, and Zambia Consolidated Copper Mining Investment Holding (ZCCM-IH).

4.2.4 Challenge questionnaire survey

A challenge questionnaire survey having a scale rating from 0 to 5 was used to determine the intensity of the challenges in the ASMM sector. The questionnaire was issued to forty-three respondents to determine the intensity of the challenges in the sector. The intensity rating of each challenge was calculated as:

$$C = \frac{\sum_{i=1}^{n} S_i}{N} \quad [1]$$

Where C is the challenge intensity rating, S_i is the ith challenge score, and N is the number of respondents.

4.3 Data analysis process

The intensity ratings of the identified challenges were determined using Equation 1. The challenges were then classified into causal and effect groups using the DEMATEL technique (see Appendix A) based on inputs from twenty mining experts with a minimum of 2 years of experience in the ASMM sector. Lastly, strategic policy responses for addressing or mitigating the causal challenges were prescribed. Perceptual growth strategies of the sector were uncovered through high-level stakeholder consultations. A proposed framework for growing the ASMM sector was proposed based on identified strategic policy responses to the identified causal challenges, and perceptual growth strategies obtained from high-level stakeholder consultations.

4.4 Sampling technique

This study uses both convenience and purposive sampling. Firstly, convenient sampling was used to sample easily accessible respondents. Subsequently, purposive sampling was employed to select respondents from the convenience sample who have a minimum of two years of mining experience in the manganese sector. A span of 2 years was chosen because this represents a reasonable time frame for the

5.0 DATA COLLECTED

respondent to be acquainted with various challenges facing the sector.

Table 1 presents the data that was collected from the three study areas, namely, Mkushi, Serenje, and Mansa districts. It must be noted that the data presented in this Section is a synopsis and not exhaustive.

Data	Study Area		
	Mkushi	**Serenje**	**Mansa**
ASM companies visited	Datong Industry Corporations (Manganese Washing Plant)	(i) Kampoko Resources Ltd (ii) Kabundi Mineral Resources Ltd (iii) Luapula Mining Company (a joint venture of MMRP mining co. Ltd and Brigade Constructions Ltd)	(i) Katuta Mining Company (ii) Mondell Commodities Company (iii) Peco Mining Ltd (iv) Mathkat company
Price of manganese (USD/tonne)	40 – 80	40 – 80	40 – 80
Average grade of manganese in visited areas	50 – 55	50 – 55	50 – 55
Buyers of manganese	Chinese, Indians, and locals	Chinese, Indians, and locals	Chinese, Indians, and locals
Price determination of manganese	Negotiation based on average grade	Negotiation based on average grade	Negotiation based on average grade
Technology employed in visited mining areas	Rudimentary to semi-mechanised	Semi to highly mechanised	Rudimentary to semi-mechanised
People involved in mining	Men and Women	Women and Men	Women and men
Level of organisation	Ranges from being disorganised to being highly organised	Ranges from being disorganised to being highly organised	Ranges from being disorganised to being highly organised
Smelters operating in the area	None	Chi Metal, PLR, Kanona (Smelters are in Pensulo area)	None

6.0 DATA ANALYSIS AND DISCUSSION OF RESULTS

Table 1 Data Collected from Study Areas

6.1 Identification and ranking of causal and effect challenges

Challenges affecting the economic growth of Zambia's ASMM sector in the study areas (i.e., Mkushi, Serenje, and Mansa) were identified by desktop review, interviewing and brainstorming academics, directors at mine sites, artisanal and small-scale miners, and other mining experts from government institutions. The challenges were classified into operational, financial, legal and regulatory, and auxiliary classes as shown in **Table 2**.

Table 2 List of identified Challenges in Zambia's ASMM Sector

Category	List of challenges	Symbol
Operational	Lack of geological information	C1
	Lack of mining equipment to exploit orebodies	C2
	Lack of skilled labour force	C3
	Use of inefficient mining methods	C4
	Poor mining practice	C5
	Lack of processing facilities	C6
	Use of inefficient processing techniques	C7
	Inadequate road infrastructure to and from the mine site	C8
	Limited supply of electrical power to mine sites	C9
	Lack of robust mine planning	C10
Financial	Lack of a readily available lucrative market	C11
	Lack of a marketing strategy	C12
	Low manganese prices	C13
	High tax rates	C14
	High operating cost	C15
	Lack of fiscal incentives to support the growth of the sector	C16
	Lack of start-up and working capital	C17
Legal and Regulatory	Weak regulations and laws to support the growth of the sector	C18
	Lack of institutional capacity to support the growth of the sector	C19
	Bureaucracy in obtaining a mining license	C20
	Lack of implementation of regulations that support the growth of the sector	C21
Auxiliary	Lack of technical and financial knowledge	C22
	Presence of illegal miners	C23
	Problems of occupational health and safety	C24

The intensity ratings of the challenges were calculated using Equation 1. Table 3 shows a summary of the intensity ratings of the challenges for each research area. Subsequently, the ratings were averaged to determine the aggregate intensity rating of the challenges in all three areas.

Table 3 Intensity Ratings of Challenges in the Study Areas

	Intensity rating – study area			Average Intensity Rating	Classification of challenges based on aggregate intensity rating	Intensity ranking of challenges
	Mkushi	Serenje	Mansa			
C_1	4	4	4	4	High	2
C_2	3	4	3	3	Medium	3
C_3	3	3	3	3	Medium	3
C_4	4	4	4	4	High	2
C_5	4	4	4	4	High	2
C_6	4	3	4	4	High	2
C_7	2	2	3	3	Medium	3
C_8	3	3	4	3	Medium	3
C_9	3	3	4	4	High	2
C_{10}	4	4	4	4	High	2
C_{11}	2	2	2	2	Low	4
C_{12}	2	3	2	2	Low	4
C_{13}	4	4	4	4	High	2
C_{14}	4	4	4	4	High	2
C_{15}	3	4	4	4	High	2
C_{16}	4	4	3	4	High	2
C_{17}	4	4	4	4	High	2
C_{18}	2	3	3	3	Medium	3
C_{19}	3	4	3	3	Medium	3
C_{20}	3	3	3	3	Medium	3
C_{21}	3	3	4	3	Medium	3
C_{22}	4	4	4	4	High	2
C_{23}	5	4	4	4	High	2
C_{24}	5	5	5	5	Very High	1

From the results in **Table 3**, it can be deduced that occupational health and safety challenge was the highest having an intensity rating of 5 which equates to a very high classification. Thirteen challenges were classified as being high, namely, lack of geological information, use of inefficient mining methods, poor mining facilities, limited supply of electrical power to mine sites, lack of robust mine planning, low manganese prices, high tax rates, high operating cost, lack of fiscal incentives to support the growth of the sector, lack of startup and working capital, lack of technical and financial knowledge, and presence of illegal miners. Eight challenges were classified to have a medium intensity, namely, lack of mining equipment to exploit orebodies, lack of skilled labour force, use of inefficient processing techniques, weak regulations and law, lack of institutional capacity to support the growth of the sector, bureaucracy in obtaining mining licenses, and lack of implementation of regulations. Lastly, two challenges were classified as being low, namely, lack of a readily available lucrative market and lack of a marketing strategy.

After determining the intensity ratings of the challenges, they were then classified into causal and effect groups. The theory of the DEMATEL technique explicated in Appendix A was applied for this undertaking. **Table 4** shows the ranking and classification of the challenges into causal and effect groups.

Table 4 Causal and Effect Challenges

Challenge	R+C	R-C	Causal-Effect classification
C_1	0.92	0.16	Cause
C_2	0.73	-0.15	Effect
C_3	0.64	0.26	Cause
C_4	0.91	-0.48	Effect
C_5	0.99	-0.78	Effect
C_6	0.47	-0.25	Effect
C_7	0.51	-0.46	Effect
C_8	0.13	-0.02	Effect
C_9	0.19	-0.02	Effect
C_{10}	0.65	-0.38	Effect
C_{11}	0.17	-0.17	Effect
C_{12}	0.11	-0.05	Effect
C_{13}	0.41	-0.20	Effect
C_{14}	0.65	0.65	Cause
C_{15}	0.78	-0.65	Effect
C_{16}	0.49	0.49	Cause
C_{17}	1.23	0.79	Cause
C_{18}	0.56	0.56	Cause
C_{19}	1.15	1.15	Cause
C_{20}	0.32	0.32	Cause
C_{21}	0.15	0.00	Effect
C_{22}	1.15	1.00	Cause
C_{23}	0.98	-0.44	Effect
C_{24}	1.32	-1.32	Effect

When classifying causal challenges, one is interested in the causality rating which means the degree to which it causes other challenges. The causality ratings of the challenges in Table 5 were obtained by normalizing the prominence parameter (r_j+c_j) under the DEMATEL technique (see Equation 2)

$$F_i = \frac{5*(r_i+c_i)}{\beta}, \quad 0 \leq F_i \leq 5 \qquad [2]$$

Where F_i is the causal rating of the ith challenge (expressed to the nearest whole number), and r_i+c_i is the prominence parameter of the ith challenge, and β is the maximum value of (r_j+c_j) among all the challenges. A ranking of 5, 4, 3, 2, and 1 mean a causality rating of very high, high, medium, low, and very low, respectively. The causal ratings and rankings of the challenges are summarized in Table 5.

Table 5 Causal Rating of the Causal Challenges

Challenge	Causal rating	Classification of challenges	Causal ranking
C19	3	Medium	4
C22	2	Low	3
C17	2	Low	4
C14	2	Low	4
C18	5	Very High	4
C16	2	Low	3
C20	4	High	3
C3	1	Very Low	3
C1	4	High	4

A causality–intensity rating map of challenges was generated to show the combined intensity and causal ratings of the challenges. From Figure 4, the lack of startup and working capital has the highest causality and intensity rating. This is followed by a sequential ranking of:

(i) Lack of technical and financial knowledge;

(ii) Lack of institutional capacity to support the growth of the sector;

(iii) Lack of geological information;

(iv) High tax rates and lack of fiscal incentives;

(v) Lack of skilled labour force and weak regulations and laws; and

(vi) Bureaucracy in obtaining mining licenses

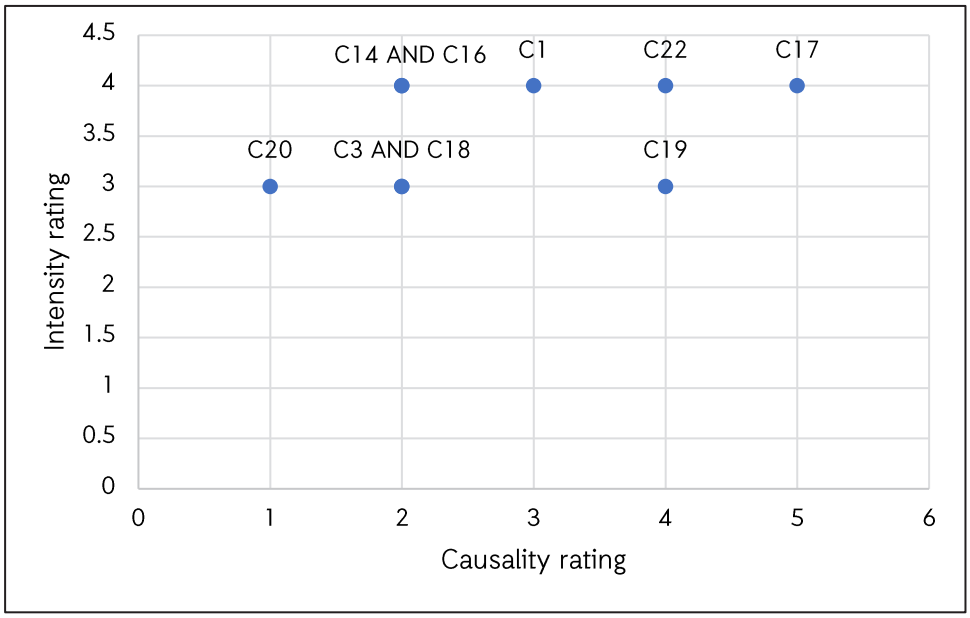

Figure 4 Causality – Intensity Ranking Map of Challenges

6.1.1 Interdependency of causal and effect challenges

Based on the group direct influence matrix from the DEMATEL technique, the relationship between causal and effect group challenges can be mapped out as shown in Figure 5. From the figure, it can be deduced that high tax rates, low manganese prices, lack of marketing strategy, high operating cost, lack of fiscal incentives, lack of an easily available lucrative market affects lack of capital because it means artisanal and small-scale miners cannot generate and plough back financial resources into their operations for growth.

Secondly, lack of startup and working capital has an impact on lack of skilled labour force, lack of geological information, and lack of processing facilities and equipment to exploit orebodies. This is because having a lack of capital on the part of the artisanal and small-scale miners means they cannot afford to hire skilled labour, map out reserves, and purchase processing facilities. These challenges have a subsequent impact on the miners to undertake sound mine planning, and use efficient mining and processing techniques. These problems further culminate into other challenges of poor mining, safety, health, and environmental practices at ASMM sites.

Thirdly, legal and regulatory challenges including weak regulations and laws, lack of institutional capacity to support the growth of the sector, and bureaucratic framework of obtaining mining licenses have an impact on some operational challenges, namely, lack of electrical power, lack of adequate road infrastructure, and presence of illegal mining activities in the mining areas. This further results in safety, health, and environmental problems.

6.2 Quantitative review of high tax challenge

This section undertakes a quantitative review of the high tax rate challenge by generating technical-financial spreadsheet models of ASMM operations. Four ASMM projects were created using the information collected from the field. The results of the analysis show that the current taxation regime applied to the four ASMM operations generates Average Effective Tax Rates (AETRs), and Marginal Effective Tax Rates (METRs) as shown in Table 6. From this Table, it can be deduced that the AETR of the current taxation regime is above 39% for all four projects. The AETR for one project was as high as 75%. This means the government would take 75% of the ASM project pre-tax cash flows before operating costs are knocked out from its revenue base. The METR which is the taxation on the additional dollar of income earned shows that all four projects have rates above 41%. The results of this quantitative review or assessment collaborate with the results from Table 3 which show the intensity rating of the challenge to be high in all three areas. This state of affairs is a recipe for illegal mining activities because illegal miners will fear to step into the formal space in fear of the hard-earned production being taxed away. This further culminates in poor safety, health, and environmental practices at mine sites.

Table 6 Current Taxation Regime in ASMM Sector

ASMM project	AETR (%)	METR (%)
1	39	41
2	43	51
3	75	57
4	43	52

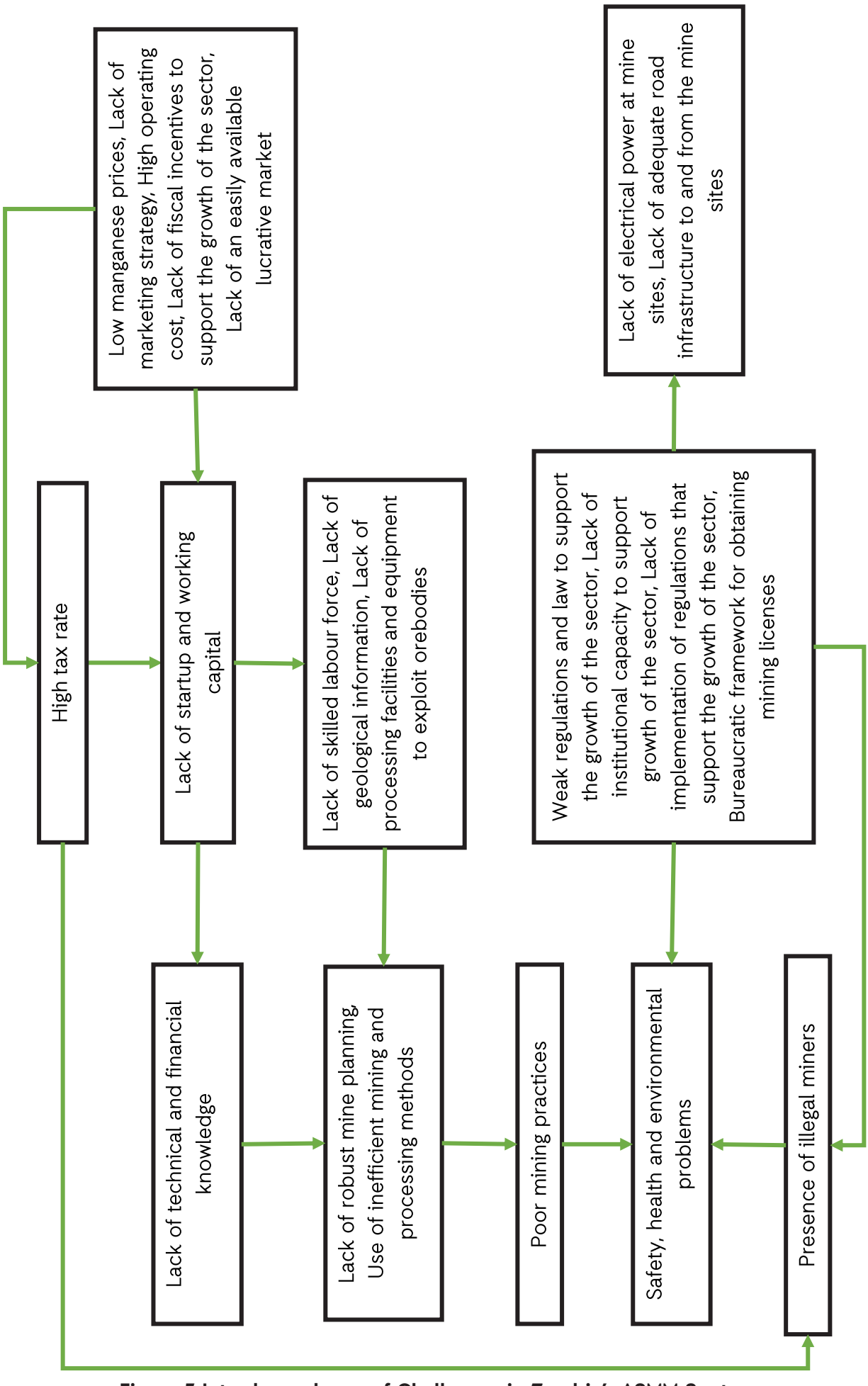

Figure 5 Interdependency of Challenges in Zambia's ASMM Sector

6.3 Strategic policy responses to address causal challenges

The strategy for growing the ASMM sector will require addressing the causal challenges identified in Table 5. Resolving these challenges will have an indirect impact to resolve the effect challenges. Table 7 shows the strategic policy responses that can be initiated to resolve the causal challenges. Through these responses, the barriers impeding the growth of the ASMM sector can be mitigated. It must be mentioned that all the causal challenges identified from the DEMATEL technique are primary factors that impede the integration of the ASMM sector into the formal economy.

Table 7 Strategic Policy Responses to Grow the ASMM Sector

Challenge	Strategic Policy Responses
C_1	Increase funding to the Geological Survey Department using a portion of mineral royalty or any other financing mechanism
C_3 & C_{22}	• Undertake skills development of ASMM operators by organising training workshops through the regional bureaus • Ministry of Mines to engage the University of Zambia, School of Mines and the Copperbelt University, School of Mines and Mineral Sciences to train artisanal and small-scale miners on safe, efficient, and effective techniques of mining and processing manganese
C_{14}	Lower Average Effective Tax Rate (AETR) through robust evaluation of tax policy
C_{16}	Ministry of Small Medium Enterprise Development (MSMED) and Zambia Development Agency (ZDA) to create more incentives that support the growth of the ASMM sector
C_{17}	Government to aid the financing of ASMM operators by deploying mine equipment
C_{18}	Include a section within the current legislation that speaks directly to the artisanal and small-scale mining sector and strengthen the mining policy to practically deal with problems of the ASMM sector
C_{19}	Strengthen regional mining bureaus with the much-needed technology, human resource, and infrastructure to provide technical support to ASMM operators
C_{20}	Reduce bureaucracy of obtaining mining licenses through a decentralisation process, where regional mining bureaus can award mining and non-mining rights

6.4 Perceptual strategies for growing the ASMM

Perceptual growth strategies for growing the ASMM sector were obtained by consulting high-level stakeholders. Table 8 shows a summary of their responses to the question of what can be done in the ASMM sector to initiate growth.

Table 8 Stakeholder's Responses

Respondent No.	Response
1	• ASMM sector needs to be formalised through the formation of cooperatives • ASMM sector needs to have a sector-specific taxation regime • Provide access to finance through loans • Undertake workshops to train artisanal and small-scale miners on financial and technical management of mines • ZCCM-IH should engage in production-sharing agreements with miners by receiving payment in actual production terms once technical extension services are provided

2	• Create local demand for manganese by opening up forward vertical integration linkages e.g., the creation of smelters, steel industries, and battery manufacturing plants using steel as a key input ingredient • The fiscal burden needs to be lowered for the artisanal and small-scale miners • Increased monitoring at ASMM sites and implement legal actions against ASM operators not complying with the law • MMMD or ZCCM-IH should engage in production sharing as a means of providing equipment • Formalise the ASMM sector through cooperatives
3	• Train artisanal and small-scale miners to be creditworthy • The mining equipment challenge needs to be resolved through production sharing by ZCCM-IH and the small-scale miners. However, a mechanism must be put in place to ensure corruption is eliminated • Taxation should be lowered for the ASMM sector • Formalise ASM sector through cooperatives • Link the manganese ASM sector to the wider economy (e.g. steel, battery, and agriculture)
4	• Provide artisanal and small-scale miners with equipment • Production sharing between ASM operators and ZCCM-IH • Government to set up smelters and feed the smelters with manganese ore obtained through production sharing between ASM operators and ZCCM-IH, and that confiscated from illegal miners • ASM operators should be given a lower fiscal regime (high tax rates encourage informality and/or illegality) • Formulate policy that creates a conducive business environment that supports the setup of downstream manufacturing plants that use manganese as feedstock e.g. steel, battery, and agriculture plants
5	• Create a policy that will bring in more investors that will work with the locals to improve community livelihood • More policing is required in areas where there are suspected illegal mining activities
6	• Government should engage in Public-Private Partnerships in the manganese ASM sector • Regional bureaus to be strengthened to curb illegal mining activities
7	• Formulate good policy in the ASMM sector to encourage growth • ASMM needs to undergo an intensive formalisation process • Reduce exploration and license fees • Government should erect its washing plants and smelter facilities
8	• ASM operators should pay lower council fees, mining license fees, and taxes • Buyers should be compelled to stop buying from ASM operators with no licenses to encourage formalisation • Provide access to finance for ASMM operators

6.5 Proposed strategy for growing the ASMM sector

This section presents a proposed strategy for growing the manganese mining sector through ASMM. The strategy draws on the strategic policy responses in Section 6.3 and elements of the perceptual strategies highlighted in **Table 8**.

Step 1: Formalizations of the ASMM sector by primarily addressing causal challenges
Government should move aggressively into the mining areas of Serenje, Mkushi, and Mansa to formalize ASMM activities. This can be attained by addressing the challenges highlighted in Table 2. Causal factors should be of primary interest because these tend to cause other problems. These challenges can be mitigated through the strategic policy responses highlighted in Table 7. These challenges cannot be resolved comprehensively and at the same time because of the fiscal pressure exerted on the government's operational budget to support the mining sector. Therefore, a plan has to be rolled out in terms of which causal challenges must be prioritized based on the operational budget.

Step 2: Government, local and foreign investors to partner with ASMM operators

Government, local and foreign investors should partner with the miners through production sharing agreements. These agreements will provide a platform for these players to offer technical and financial assistance to the miners. The government, local and foreign investors will have to be paid based on the actual value of production which equates to the value of the technical and financial assistance rendered. Equipment owners are also included as part of the local or foreign investors. These players can move into mining areas to agree with artisanal and small—scale miners on equipment lease agreements paid through actual production or cash. These agreements are encouraged because of the high-intensity profile of the lack of equipment challenge in the mining areas (see Table 3).

Step 3: Setting up mineral processing facilities

Government, local and foreign investors solely or through Joint Venture Partnership (JVP) should set up mineral processing facilities, namely, washing and smelting plants. These facilities will ensure forward vertical integration of the sector through value addition activities. The feed to these facilities will be the manganese obtained from the miners, government, local and foreign investors, or JVP between any of these parties.

Step 4: Creation of manganese market hubs by the government

Government should facilitate the creation of open areas which can be treated as market hubs. The hubs will serve as trade centers where different players will buy and sell manganese. However, a robust trading mechanism for these hubs will need to be created by the Ministry of Mines and Minerals Development. One of the activities will be the need to create price bands based on average grade, particle size, and extent of value addition. This will limit the exploitation of the sellers by the buyers.

Step 5: Government to create a conducive policy environment to support downstream manufacturing plants

The government needs to create favorable policies that support the creation of downstream manufacturing plants that use manganese as feedstock to generate their final product. Two industries that are of paramount importance are steel and battery manufacturing. For steel production, primary ingredients like coke, iron, and limestone are needed. Fortunately, Zambia boasts of a significant amount of these mineral reserves dotted across the country. For battery manufacturing, we have been through this route before, when Mansa batteries was operational. Therefore, there is a need to revive this industry with manganese acting as an important feedstock in the manufacturing process of the battery cathodes. When properly engineered these business initiatives can transform Serenje, Mansa, and Mkushi mining areas into industrial hubs providing a form of livelihood to the locals. This

will subsequently lead to poverty reduction. This will culminate in macroeconomic growth because of increased foreign exchange, export earnings, employment, and domestic revenue generation through taxation and other fiscal instruments.

Figure 6 shows the flow of manganese production under the proposed strategy from the formalized ASMM sector to the external market and/or downstream industries. From the Figure, it can be deduced that the Zambian Government, local and foreign investors can obtain manganese run-of-mine (ROM) ore from the formalized ASMM sector through purchase at sites or production sharing agreements. The obtained production can be sent to the washing plants or directly to market hubs to be sold. Smelter owners can add value to the manganese to generate silico and ferromanganese which can be fed into downstream industries or exported to the external market.

6.6 Discussion

This research study had the objective of devising a strategy for growing the ASMM sector in Zambia to induce economic development and poverty reduction. The study was undertaken in three areas, namely, Mkushi, Serenje, and Mansa. These areas were selected because of the significant amount of ASMM activities currently taking place. From the results of the study, it was deduced that twenty-four challenges are currently affecting the economic growth of the ASMM sector. In the context of this research, economic growth means the ability of the ASMM sector to increase production from the current level.

The DEMATEL technique was applied to classify the challenges into causal and effect groups. Nine causal and fifteen effect challenges were identified. The interdependencies of the challenges are graphically represented in Figure 5. As can be seen from the Figure, the Government of the Republic of Zambia (GRZ) should be primarily obsessed with resolving causal challenges because they can influence the generation of other problems. The strategic policy responses highlighted in Table 7 must be implemented to address these challenges. It must be stressed that once these challenges are resolved it will go a long way in integrating the ASMM sector into the formal economy.

The intensity of the high tax rate challenge was quantitatively reviewed using collected technical-financial information from four ASM projects operating in the study areas. Results show that the current taxation regime exerts a high fiscal burden on the projects. The tax regime generates AETRs and METRs, above 39% and 41%, respectively. This collaborates the results in Table 3 which show the intensity rating of the challenge to be high in all three areas.

Perceptual strategies for growing the ASMM sector were obtained through high-level stakeholder consultations with officials from the MMMD, Zambia Chamber of Mines, Academia, and ZCCM-IH. The consultations coupled with strategic policy responses of resolving causal challenges fed into the process of crafting a proposed strategy for growing the manganese mining sector. The proposed strategy was generated through the lens of ASM because these are the dominant players in the sector when compared to large-scale mining. The proposed strategy is a five-step process that involves:

(i) Formalisation of the ASMM sector by primarily resolving the causal challenges;

(ii) Partnering of government, local and foreign investors with artisanal and small-scale miners;

(iii) Setting up of mineral processing facilities;

(iv) Creation of market hubs; and

(v) Creation of a conducive policy environment to support downstream manufacturing plants.

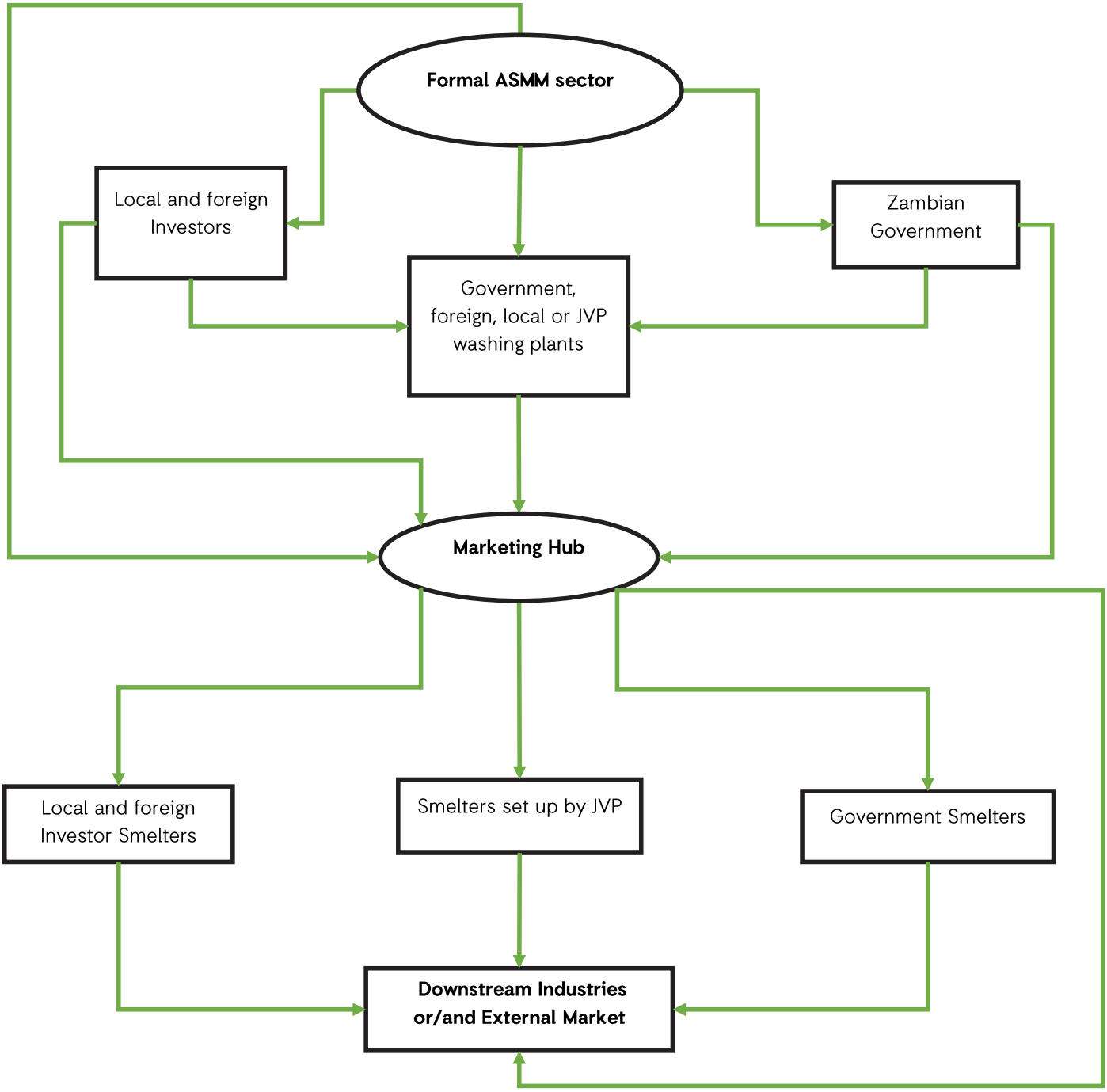

Figure 6 Flow of Manganese Production under proposed strategy

6.7 Social-economic transmission effect of challenges

The proposed strategy has a transmission effect to reduce poverty and induce economic development in mining host communities. Figure 7 shows the social-economic transmission effect of the proposed strategy. From this figure, it can be deduced that elements of the proposed strategy can lead to the increased creation of employment through the setting up of smelters, washing plants, and downstream industries such as steel and battery manufacturing.

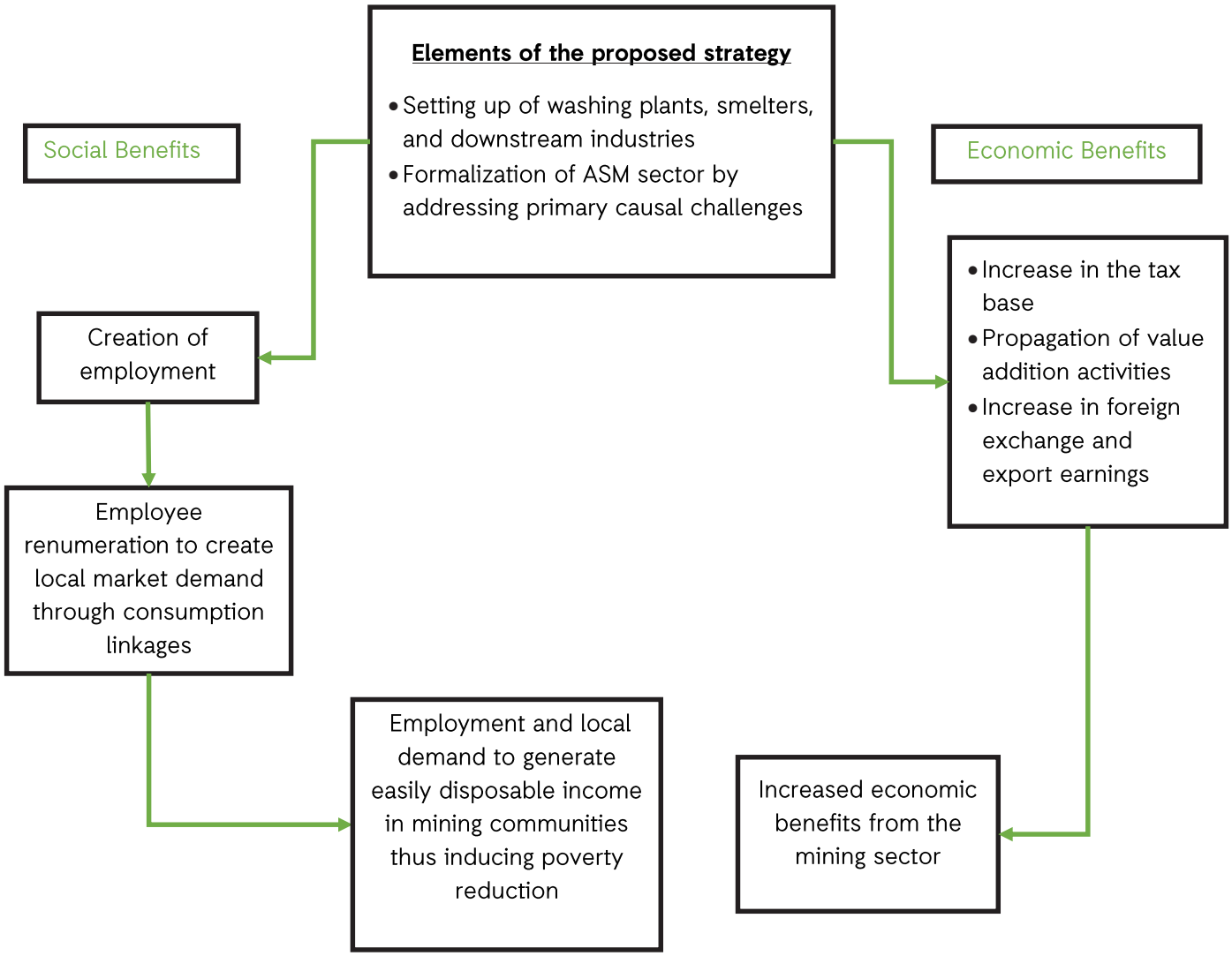

Figure 7 Socio-economic transmission effect of the proposed strategy

In other words, the proposed strategy has the potential to create industrial hubs. This will lead to a potential increase in employment levels and the possible subsequent creation of consumption linkages by increasing local market demand through employee remuneration. This interplay of factors will lead to the addition of disposable income in people's pockets thus somewhat reducing poverty and income inequality gaps. On the economics side of things, the proposed strategy has the potential to:

(i) Increase the tax base in the mining sector;

(ii) Increase FDI, value addition, and employment activities through the set up of washing plants, smelters, and downstream industries;

(iii) Increase export and foreign exchange earnings; and

(iv) Create a platform to enhance the propagation of local content in the mining sector.

These activities will somewhat lead to the country increasing the benefits taken from manganese and the mining sector as a whole through production, consumption, and fiscal linkages.

CONCLUSION AND RECOMMENDATION

This study was focused on devising a strategy for growing the manganese mining sector through the lens of ASM operations. The proposed strategy hinges on the strategic policy responses of resolving causal challenges in the ASMM sector and perceptual strategies obtained through high-level stakeholder consultations. The proposed strategy is a five-step process that involves, formalisation of the ASMM sector by primarily resolving causal challenges; partnering government, local and foreign investors with artisanal and small-scale miners; setting up mineral processing facilities; creating market hubs, and generation of a conducive business environment through policy to support downstream manufacturing plants. Feeding manganese to downstream industries such as steel and battery manufacturing will culminate in poverty reduction and above all, it will induce macroeconomic growth because of increased foreign exchange, export earnings, employment, and domestic revenue generation through taxation and other fiscal instruments. It is important to mention that the steps of the proposed strategy can be undertaken solely or simultaneously depending on the economic dynamics at play.

Another area that has the potential to initiate poverty reduction within the proposed strategy is the creation of mineral processing facilities and smelters which can employ a large number of locals but at the same time generate a platform for jump-starting and proliferating value addition activities in the sector. Additionally, partnerships among miners, government, local, and foreign investors will ensure ASMM operations grow to address poverty levels in mining host communities through the creation of employment and provision of other important services such as education and health. In going forward, it is recommended that government adopts the proposed strategy as a way of growing the manganese mining sector through the lens of ASMM.

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APPENDIX A

THEORY OF THE DEMATEL TECHNIQUE

The solution framework of the traditional DEMATEL technique is summarized into four steps as follows (Yazdi et al., 2020):

Step 1: Generating the group direct Influence matrix

Assume that there are n factors defined as F={F_1,F_2,...,F_n} in a studied complex system. To examine the relationships between all identified factors several decision-makers l, in a group DM={βDMβ_1,βDMβ_2,..., βDMβ_n} are asked to specify how much factor F_i has a direct effect (influence) on factor F_j by utilizing the five different integer scales as "Very High Influence (4)", "High Influence (3)", Medium Influence (2)" "Low Influence (1)", and "no influence (0)". Then the individual direct influence matrix βZ_k=[βZ_ijβ^k] β_nxn provided by the kth expert can be formed, where all principal diagonal elements are equal to zero and βZ_ijβ^k represents the judgement of the decision-maker βDMβ_l on the degree to which factor F_i affects factor F_j. By aggregating all the l decision makers' input, the group direct-influence can be obtained using Equation A-1.

$$Z_{ij} = \frac{1}{l}\sum_{k=1}^{l} z^k{}_{ij} \quad i,j = 1,2,\dots,n \qquad \text{[A-1]}$$

Step 2: Establish the normalized direct influence matrix

The normalized direct-influence matrix X=β[x_ij]β_nxn is obtained using Equations A-2 and A-3

$$\mathrm{X} = \frac{\mathrm{Z}}{s} \qquad \text{[A-2]}$$

$$\mathrm{s} = \max\left\{\max_{1 \le i \le n}\sum_{j=1}^{n} Z_{ij}, \max_{1 \le j \le n}\sum_{i=1}^{n} Z_{ij}\right\} \qquad \text{[A-3]}$$

Where all elements of matrix X are in the interval zero to one, and 0≤∑_(j=1)^nβx_ij ≤1. In Equation A-3, s denotes the biggest value among the sums of each row and each column.

Step 3: Construct the total influence matrix T

Using the normalized direct influence matrix X, the total influence matrix T=β[t_ij]β_nxn is then computed by summing the direct effects and all of the indirect effects by:

$$T = \lim_{h\to\infty}(X + X^2 + X^3 + \cdots + X^h) = X(I - X)^{-1} \qquad \text{[A-4]}$$

Step 4: Produce the Influential Relation Map (IRM)

At this step the vectors R and C, representing the sum of the rows and the sum of the columns from the total influence matrix T, are defined by the following formulas:

$$R = [r_i]_{nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1,} \qquad \text{[A-5]}$$

$$C = [c_j]_{1xn} = \left[\sum_{j=1}^{n} t_{ij}\right]_{1xn,} \qquad \text{[A-6]}$$

Where r_i is the ith row in the matrix T and displays the sum of the direct and indirect effects from factor F_i to the other factors. Similarly, c_j is the jth column sum in the matrix T and depicts the sum of direct and indirect effects that factor F_j is receiving from other factors.

manganese exports have relatively increased (see Figure 1). However, production took a downward trend from 2017 to 2019 but began an upward trajectory from 2020 (see Figure 2).

Let i=j, where i,jβ{1,2,...,n}, (R+C) called “Prominence” is a horizontal axis vector signifying the degree of control that the factors play in the studied system. Similarly, (R-C) known as “Relation” is computed for the vertical axis and specifies the net effect that the factor contributes to the system. If (r_j-c_j) is positive, factor F_j has a net influence on other factors and can be grouped into cause group, if β(rβ_j-c_j) is negative, then the factor F_j is being influenced by other factors and should be grouped into the effect group. Finally, an IRM can be created by mapping the data set of (R+C,R-C), which provides valuable insights for decision making.

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