RARE EARTH ELEMENTS (REE)
Value Chain Analysis for Mineral Based Industrialization in Africa

2021

AFRICAN DEVELOPMENT BANK GROUP

African Natural Resources Centre

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Please cite the work as follows:
African Natural Resources Centre (ANRC). 2021. Rare Earth Elements (REE). Value Chain Analysis for Mineral Based Industrialization in Africa. African Development Bank. Abidjan, Côte d'Ivoire.

Foreword

The African Natural Resources Centre (ANRC) is an entity of the African Development Bank (Bank) dealing with natural resources management. The mandate of ANRC is to assist African governments maximize development outcomes derived from Africa's natural resources by boosting the capacity of the governments to achieve inclusive and sustained growth. ANRC delivers its mandate through cutting edge knowledge, conducting high-impact policy analysis, dialogue and providing technical assistance to help support African countries in natural resources planning, policy making, investment and governance. The work covers both renewable (water, forestry, land, and fisheries) and non-renewable (oil, gas and minerals) resources.

Currently, ANRC is running a local content and value addition flagship which seeks to support the Bank's regional member countries in developing policies, investment plans, governance frameworks and effective implementation strategies for local content and value addition in the extractive sector. In a bid to industrialize Africa which is one of the high five priorities of the Bank, the ANRC is evaluating opportunities for value addition to selected minerals. Rare Earth Elements (REE) are useful in the manufacture of modern high-strength magnets and they also constitute vital inputs for a growing range of mass consumer electronics and some military applications. Whilst significant reserves have been found in Burundi, Malawi and South Africa, there are also existing projects in several African countries that have delineated some significant resources. These countries include Tanzania, Zambia, Namibia, Kenya, Madagascar, and Mozambique.

The Rare Earth Elements (REE) study is intended to identify opportunities and challenges for value addition to REE deposits in Africa and proposes options for optimising the REE value chain in Africa. The intention is to explore further the African situation in a bid to develop REE-based products such as magnets and electronic components to contribute to the world's low carbon future. With the development of this market segment, the study would be contributing to stemming the tide of raw material exports and maximizing the benefits along the REE value chain.

Africa's industrialization can be achieved through the wise use of its enormous natural resources, including mineral reserves. Currently, it is estimated that Africa holds 30% of the world's mineral reserves (USGS, 2020) and accounts for more than 20% of the global annual production of five key minerals namely, 80% of global platinum production, 77% of cobalt, 51% manganese, 46% of diamonds, 39% chromium and 22% of gold. However, most of these minerals are exported in their raw state without value addition and the sector is not integrated with the other sectors of African economies to ensure optimization of benefits.

The work in local content and value addition by ANRC is therefore designed to help address the challenges that hinder value addition and deepen domestic linkages in the economies of African countries. This is also in line with the Bank's industrialization strategy that aims to support the natural resources sector to continue playing a leading role in contributing to the industrialization of Africa. Industrialization is an engine for economic growth. It leads to technological innovation, job, and trade creation, and lays the foundation for the services sector. The availability of diverse mineral wealth in Africa is therefore one of the region's strongest advantages and value proposition to industrialize Africa.

Among other knowledge products in the local content and value addition flagship in Africa's Extractive Sectors that the ANRC is undertaking include:

- Lithium cobalt value chain analysis for mineral based industrialization in Africa
- Towards a framework for local content policy development in the mining sector in Ethiopia
- Towards a framework for local content policy development in the petroleum sector in Ethiopia
- Value chain analysis for the oil sector - potential contributions to African economies
- Enhancing the performance of African national oil companies
- Assessment of supplier development programmes (SDPs) in the extractive sector in Africa: strengths, weaknesses, opportunities and critical success factors;

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

List of Acronyms and Abbreviations

AfCFTA	African Continental Free Trade Area
AfDB	African Development Bank
AIM	Alternative Investment Market
AMDC	African Minerals Development Centre
AMREC	African Mineral and Energy Management System
AMV	Africa Mining Vision
ASX	Australian Stock Exchange
Ce	Cerium
CREO	Critical Rare Earth Oxides
Dy	Dysprosium
EAC	East African Economic Community
Er	Erbium
Eu	Europium
FDI	Foreign Direct Investment
Gd	Gadolinium
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMIS	Geological Information Management Systems
Ho	Holmium
ICE	Internal Combustion Engine
IEA	International Energy Agency
La	Lanthanum
LoM	Life of Mine
LSE	London Stock Exchange
Lu	Lutetium
MRD	Mineral Resource Development
Nd	Neodymium
NPV	Net Present Value
PHEV	Plug-in Hybrid Electric Vehicle
PMSG	Permanent Magnet Synchronous Generators
PPP	Public Private Partnership
Pr	Praseodymium
Pm	Promethium
R & D	Research and Development
REC	Regional Economic Communities
REE	Rare Earth Element(s)
REO	Rare Earth Oxide
RMC	Regional Member Countries
RMS	Regional Member States
Sc	Scandium
Sm	Samarium
Tb	Terbium
Tm	Thulium
TREO	Total Rare Earth Oxide
TSX	Toronto Stock Exchange
UNFC	United Nations Framework for Mineral Classification
Y	Yttrium
Yb	Ytterbium

Acknowledgements

The study is part of a series of mineral value chain studies being undertaken by the African Natural Resources Centre (the Centre) of the African Development Bank to contribute towards optimizing the benefits from Africa's enormous mineral resources, as well as providing policy recommendations for Africa's low carbon future. The study follows those on gold, diamond, iron ore, lithium and cobalt which are being completed. This study resulted from an evaluation of the need to industrialize Africa using its natural resources by taking advantage of the low carbon energy transition which uses energy minerals for renewable energy needs.

This report was produced under the overall guidance of Cosmas Milton Obote Ochieng, former Director, African Natural Resources Centre of the African Development Bank. Direct supervision came from Fred Kabanda, Manager, Extractives Division, African Natural Resources Centre. The research team that worked on this study and on the resulting report was led by Jerry Ahadjie, Chief Minerals Officer, African Natural Resources Centre. The following African Development Bank staff provided critical inputs, valuable contributions, and support at various stages of the study: Arron Tchouka and Danlami Gomwalk.

The Bank gratefully acknowledges the research input of Prof. Olugbenga Akindeji Okunlola who served as the lead consultant for this study. The Bank is also grateful to the external peer reviewers; Richard Kofi Afenu, a mineral policy expert, Gift Rukezo, a mineral value chain expert and Dr. Kwasi Ampofo, lead mining analyst at Bloomberg New Energy Finance (BNEF).

The African Natural Resources Centre appreciates editorial work by Fionnuala Tennyson as well as administrative and communication support by Maali Harrathi, Eric Balogu, Eve Dagri-Pokou, Promise Aderibigbe and Joash Moitui.

Executive summary

In addition to export earnings, African countries aspire to derive greater economic value from their mineral resources. One of the most assured ways is through linkage development. Besides resource endowments, other critical factors include the international trade environment and its impact on a country's ability to successfully leverage its competitive advantage. In view of this, a value chain analysis is a useful tool to define options and permit a more thorough assessment of policy trade-offs. It is within this context that the African Development Bank initiated a study of a group of minerals with immense significance for the future. This study assesses the opportunities and challenges of harnessing the Rare Earth Element (REE) value chain to contribute to both the global transition to a low carbon future and increased socioeconomic development across African countries.

Rare Earth Elements (REEs) which hitherto were an obscure group of metals, have now assumed global significance. They are critical to modern high-strength magnets and constitute vital inputs for a growing range of mass consumer electronics and some military applications. Global production of REEs for 2019 was 213,000 MT with an estimated global reserve of approximately 120 million MT. Whilst significant reserves have been found in Burundi, Malawi and South Africa, there are also existing projects in several African countries that have delineated some significant resources. These countries include Tanzania, Zambia, Namibia, Kenya, Madagascar, and Mozambique.

The key objectives of this study were: (i) to assess the current and future status of REE reserves and value chain in Africa; (ii) to identify opportunities and challenges for value addition in the REE value chain in Africa; and (iii) to propose options or policy incentives for promoting value addition, efficiency, and equity in REE value chains in Africa. In line with these objectives, the study examined market evolution and the drivers which would support the establishment and development of the value chain in Africa. Of increasing interest is China's dominance in the REE market and the "China risk factor" resulting from its quota policy on global REE trade, which is perceived as a major supply risk by the world's largest REE consumers. This supply risk is now forcing customers to look for alternative supply sources outside China. This effectively creates opportunity for market entry for other regions of the world, including Africa.

An increase in both supply and demand was observed from an analysis of REE commodity data, and that trend is expected to continue as countries position themselves for a low carbon future. In addition, population growth and technological advancement lie at the core of REE demand. Considering these developments, the AfDB took the initiative to explore further the African scenario as part of its efforts to support the sustainable economic development of Africa. The potential of REE minerals has been highlighted as their use in magnets and electronic components are seen to contribute to the global low carbon future. As this market segment develops, the study will contribute to an exploration of whether exporting raw materials should be reconsidered and the benefits along the REE value chain maximized in the continent.

Methodology

The methodology adopted for the research was a desk-based approach supplemented with company consultations through online interviews. Based on the findings of the desk research, management personnel of four companies developing rare earth projects in Africa namely Steenkampskraal Holdings Limited ("SKKH"), Frontier Rare Earth Resources ("Frontier"), Rainbow Rare Earth Resources ("Rainbow") and Ionic Rare Earth were interviewed. The four companies provided additional data for inclusion in the study. REE demand and supply analysis was also conducted to inform policy recommendations.

REE Supply Analysis

Africa's REE ore deposits are mostly located in the eastern and southern parts of the continent. In addition to standalone REE deposits, REE minerals are also found in ore deposits of other mineral commodities as by-products, e.g., magmatic phosphate deposits and heavy mineral placer deposits (ilmenite/rutile/zircon). Fourteen major REE deposits are currently undergoing exploration or mine development in Africa. To date, the 14 deposits are estimated to have a combined mineral resource (mainly at inferred category) with potential for a contained total Rare Earth Oxide (TREO) content of more than four million tonnes.

Based on current and envisaged future market economics, Africa has the potential mineral resource to compete in the global arena. However, the development of mineral resources must be supported by business models that enable maximum benefit to the country or region. For example, smaller deposits can be mined and beneficiated up to mineral concentrate as a business model before selling the concentrate on for further processing; and large deposits can be mined and processed to the final product of REO, metals or alloys as the commercial product.

The business models must be supported at country, regional and continental levels. Regional communities can pool resources to develop regional process plants that use concentrate sourced from smaller miners like local SMEs to produce the final product. Larger scale operations run by corporations should be supported to develop integrated plants from mining through processing to the final commodity.

The dimensions of capacity inadequacy were examined, and the results show that, except for South Africa, all other potentially endowed nations have exceptionally low capacity along the value chain. Strengthening skills-specific centres of excellence within the producing Regional Member Countries (RMC) and the activation of a regional strategy in the regional economic communities (RECs) of the Southern African Development Community (SADC) and East African Economic Community (EAC) are important developments in the promotion of REE value chain development.

Demand Analysis

China remains the largest consumer of REE oxides and metals, accounting for 65 - 70% of the market share. The remainder is shared between the other developed nations. Africa relies on imports from manufacturers of REE consumer products in other continents. The high-tech industry is the driver of this industry's future growth, especially technologies linked to the manufacture of products used in green energy production and storage. The main technology is the use of magnets in wind and tidal turbines and other electronics equipment, and batteries for electric energy storage in electric vehicles (EV) and solar energy storage facilities.

Due to the imperative to reduce greenhouse gases (GHG) in the environment, fossil fuels are gradually being shown the exit door and green energy substitutes, partly driven by REE, are being developed as alternatives for the future.

Key Findings

Rare Earth Elements (REE) have unique physical and chemical properties which make them indispensable in the manufacture of high-technology products and has prompted them to be classified as critical metals. To date there are no known substitutes for their use in technologies that reduce our damage to the environment such as alternative energies to fossil fuel and storing electricity generated from solar plants. The following are the key findings:

i. Africa's REE resource and reserve potential: From a regional geological point of view, current African REE discoveries represent only the tip of the iceberg. This is because similar geological formations on the continent, which have the potential for further discoveries, are yet to be explored. The current world REE reserve stands at 120 million metric tonnes (Mt), with China's reserves representing 44 million tonnes, an equivalent of 37% of the world's total reserves. A total of 4 million tonnes has been estimated for Africa. Africa also has some of the high-grade deposits in the world. This has attracted stock market-financed exploration by junior companies as the deposits demonstrate quality REE resource availability outside China. Two of the deposits, Lofdal in Namibia and SKK in South Africa have high CREO content, an upside potential for REE value chain development in Africa as the deposits can meet the right quality of REE on the market.

ii. REE will contribute to the global transition towards a low carbon future: Strong demand for high-tech products, coupled with rapid global industrialization and population growth, has placed increased pressure on the availability of raw materials including REE. Rare earth elements will continue to be important due to their application in energy generation required by the world's pivot towards a low carbon future, and their use in high tech products. Demand for REE is expected to remain buoyant in the long term as countries continue to tighten and implement increasingly lower carbon policies, which therefore justifies the development of the value chain in Africa.

iii. Market control: The world's REE market is largely controlled by China but major consumers outside China are keen to establish alternative supply chains beyond China's jurisdiction to ensure reliable and consistent supply at predictable prices. Whilst demand continues to increase, so does the risk of China forming a monopoly on the industry. In a bid to avoid this risk, major REE consumers like the USA, the EU, Canada, Australia, Japan, and Korea are exploring options to develop alternative REE supply chains. Africa is one of the regions targeted as an alternative source of REE commodities, which presents African member states with the opportunity to develop their own REE value chains.

iv. Development of REE value chains in Africa: Companies investing in Africa focus on developing the supply side of the value chain to export REE concentrate to the Western world. There is no plan for any further development of the value chain to cater for product manufacturing such as magnet or battery manufacturing. This is the area on which Africa should focus to consolidate end-to-end development of the value chain. Three phases of the REE value chain were identified as necessary for value creation.

These are:
Upstream: Exploration, mining and beneficiation of REE into concentrate - Phase 1.
Intermediate: Metallurgical processing, separation, and reduction - Phase 2.
Downstream: Manufacturing of consumer goods such as magnets and electronic components - Phase 3.

Currently three companies are developing REE value chains in Africa. Rainbow Rare Earth mining company in Burundi, is already mining and processing ore into a concentrate it sells to TK of Germany under an offtake agreement (10,000t/annum TREO). Two other projects in South Africa, Steenkampskraal and Zandkopsdrift, are at the development stage, taking their projects to Phase 2. However, there is no company developing Phase 3 of the value chain in Africa yet. Development finance institutions such as the AfDB and the World Bank should work closely with country governments to understand the needs of these commercial REE development attempts and support the companies to develop the value chain from end to end.

Policy Recommendations

i. Improve knowledge of REE resources in Africa: African countries should consider conducting national and regional geological mapping of all potential mineralization to identify potential quantities of REE deposits. This asset will form the basis for promoting REE development to potential investors. Knowledge of the size of REE deposits allows countries to allocate exploration concessions according to investors' capabilities, for example, huge deposits can be licensed to large corporations with the financial muscle and expertise to develop the whole value chain from exploration and mining to production of separate oxide/metal/mitchmetal products, while smaller deposits can be parcelled to junior miners and SMEs to participate in the value chain. To make the maximum benefit from its natural resources, the African Minerals Development Centre (AMDC) should be strengthened to facilitate the development of these critical mineral resources in a manner that serves the interests of Africa.

ii. Provide adequate incentives to existing REE companies to develop integrated value chains: Governments should continue to promote the current industry players as forerunners of potential bigger investments. They should also develop opportunities to promote synergies between the supply and demand sides. A good example can be seen in Uganda, where Ionic Rare Earth and other mining companies are developing REE resources by mining, processing and exporting concentrates to foreign industries. Meanwhile, Uganda has Kiira Motors manufacturing Electric Vehicles (EV) using imported REE and other critical products like batteries. Kilembe Copper mine in Uganda has been mothballed for years but has large quantities of copper, cobalt and niobium, all of which are critical metals and which can meet 90% of Kiira's critical metal supply instead of imports. The missing link to develop a complete value chain is obvious in this scenario. There is a need for governmental leadership to establish an integrated industry to incentivize home-grown production of the components required.

iii. Improve the investment environment: Better governance is required if Africa is to attract the scarce exploration and mining capital needed for REE development. Firstly, governments must ensure a stable macroeconomic environment with minimal currency fluctuation. There should also be enhanced transparency in all steps of the process from the acquisition of mineral rights through to the establishment of mines. Support from the State would also be necessary to provide better logistics to limit the capital expenditure on investment, especially in remote locations. This set of conditions will be more likely to attract value chain end-to-end investors to the jurisdiction.

iv. Adapt the model of the 'Asian tigers' with elements of homegrown initiatives: Africa needs to leapfrog gradual improvement by learning from manufacturing models that have worked elsewhere, especially in China and Japan, which leveraged industrialization to create employment for their populations through value chain development. This will ensure Africa keeps pace with developments in the REE mining, beneficiation and marketing landscape.

v. Need to accelerate implementation of the value addition objective of the Africa mining vision: The The Africa Minerals Development Centre (AMDC) and its implementing partners need to accelerate progress on the mineral value addition objective on the African continent by engaging in joint ventures with foreign multinationals to transfer skills transfer minerals beneficiation, especially REEs, where Africa's skill set is currently inadequate.

vi. Local content improvement
Most immediately, governments must ensure foreign investors employ local personnel in decision-making at supervisory, management and executive level, which will leverage the impact and implementation of local content plans. Governments must also support tertiary institutions to

train graduates to meet industry requirements and companies should be encouraged to support vocational training and apprenticeships to develop their skilled and semi-skilled personnel base locally.

vii. In the long term, experienced local mining experts can transition from being employees to home-grown investors. With the help of the State, these indigenous entrepreneurs can make investments along the value chain through providing specialized services such as supply chain or technical support, though consultancy or direct investment as value chain developers, or as downstream consumer product manufacturers.

viii. This study has shown that development of the REE value chain can have a wide range of investment and capex needs, varying from as low as $10 million to about a billion dollars. Governments should therefore provide incentives for local investors to participate in the lower end of the value chain, i.e., processing REE into concentrates and large scale companies could be incentivised to develop the full value chain of REE up to products such as magnets and electronic components.

ix. Build a risk resilient environment for supply chains and operations: The African mining sector is being impacted by COVID-19 mainly because the continent consumes significant manufacturing feedstock and other industrial inputs from other continents. Whilst efforts are being made to localize these supply chains, a challenge persists due to the slow pace of implementation of continental frameworks such as the Africa Mining Vision (AMV) which provides a framework for mineral based industrialization. Accelerating the implementation of the AMV supported by holistic strategies to localize these supply chains is an important step forward. The strategy must also have provisions to urgently address the existing constraints in the mineral value chain, at country and regional levels, to facilitate the establishment of end-to-end industries to produce the consumable goods needed as input for other sectors of the economy, for instance magnets for generation of wind energy. This will lead to better availability of inputs locally and significantly mitigate the effects of pandemics, whenever they occur.

01

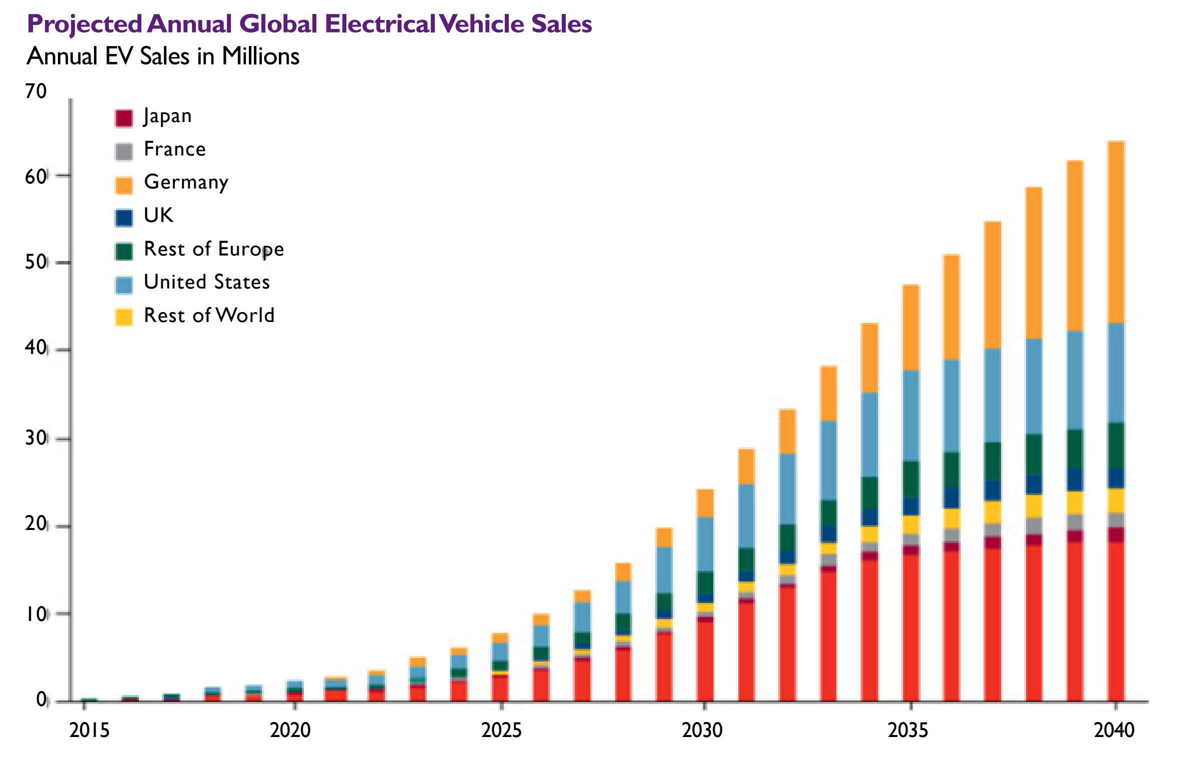
Introduction

Rare earth elements (REEs), which hitherto were an obscure group of metals, have now assumed global significance due to their role in industrial applications which contribute to a global lower carbon future. The high-technology industry is expected to continue its rapid growth, increasing the demand for REE, particularly technologies that reduce carbon use or emission into the atmosphere. REEs are critical to the manufacture of modern high strength magnets and constitute vital inputs for a growing range of mass consumer electronics and some military applications. REE compounds generally display high melting and boiling points which makes them indispensable and irreplaceable in many electronic, optical, magnetic, and catalytic applications. In terms of application, REE magnets are the most powerful magnets in the world. They make the most efficient and powerful drive motors in Electric Vehicles (EV), and wind turbines. Their strength means they can be made smaller, allowing them to be used in hi-tech applications such as smartphones, headphones, and tablets. Demand for permanent magnets will therefore drive demand for REE. Magnets are key components in the production of EV, wind farms, industrial motors, and robots. An Nd-Fe-Bs magnet contains 31- 32% REE by weight. The market is ready for transformation driven by rare earth elements.

Electric Vehicles (EVs)

Electric vehicles were once an unaffordable luxury but the global need to reduce carbon pollution makes EVs a necessity, which will eventually replace the conventional Internal Combustion Engine (ICE), or fossil fuel injection vehicles. Electric vehicle use is set to accelerate over the next 20 years as they provide the only viable alternative to replace fossil fuel vehicles, and this technology shift alone will drive REE demand to unprecedented levels. Figure 1 is the EV demand projection by Bloomberg over the next 20 years. Only 2.5% of new vehicles sold in 2019 were Battery Electric Vehicles (BEV) or Plug-in Hybrid Electric Vehicles (PHEV), amounting to just over 2 million units, with China accounting for half the market. That consumption figure is expected to dramatically rise as countries ratify new polices for low carbon future.

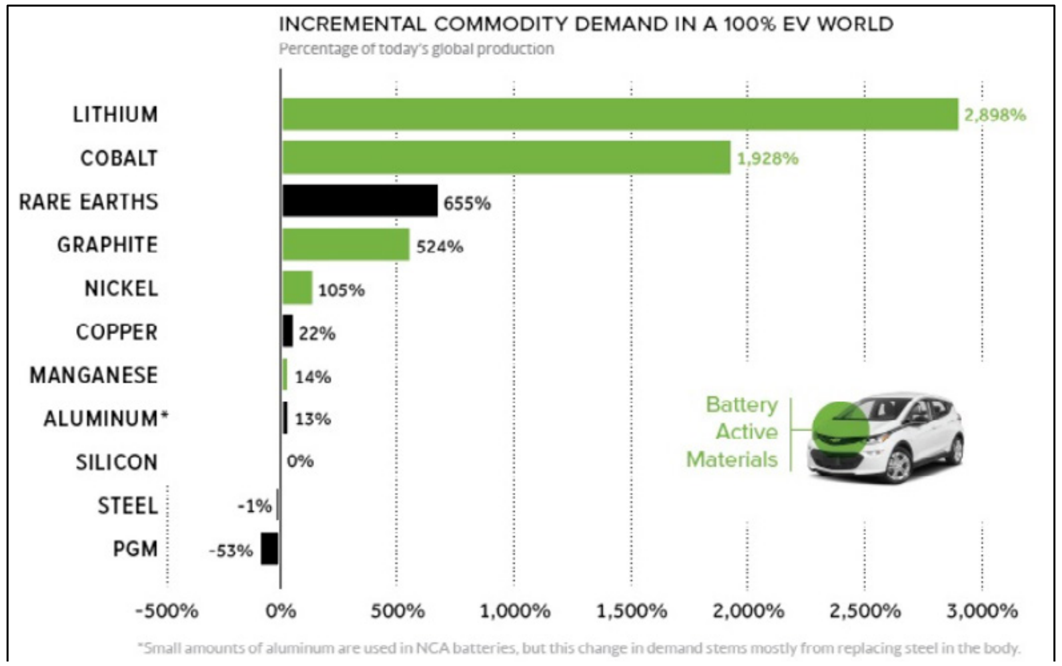
FIGURE 1: Projected Annual EV Sales.



The electric vehicle (EV) boom will cause a new wave of rare earth demand especially for Neodymium (Nd) and Dysprosium (Dy), as they are commonly used components in electric vehicle motor magnets and batteries. A standard EV requires between 1 to 2Kg of NdPr. As the EV boom takes off (especially post 2020) demand for these key REE will surge. According to Adamas[1], EV sales (excluding mild and micro hybrids) are forecasted to hit 12.5 million in 2025 and 32 million in 2030, creating a 350% increase in demand for rare earths used in traction motors. In fact, REE demand is set to surge 655% in a 100% EV world, and these figures exclude demand growth from wind turbines, drones, motors, robots and other uses. As a result, these "magnet" rare earths are forecasted to go into deficit as the EV boom takes off. Figure 2 shows the incremental commodity demand in a 100% EV world.

[1] *https://www.adamasintel.com/report/electric-growth-evs-motors-motor-materials/*

FIGURE 2: Rare earths demand set to surge 655% in a 100% EV world.

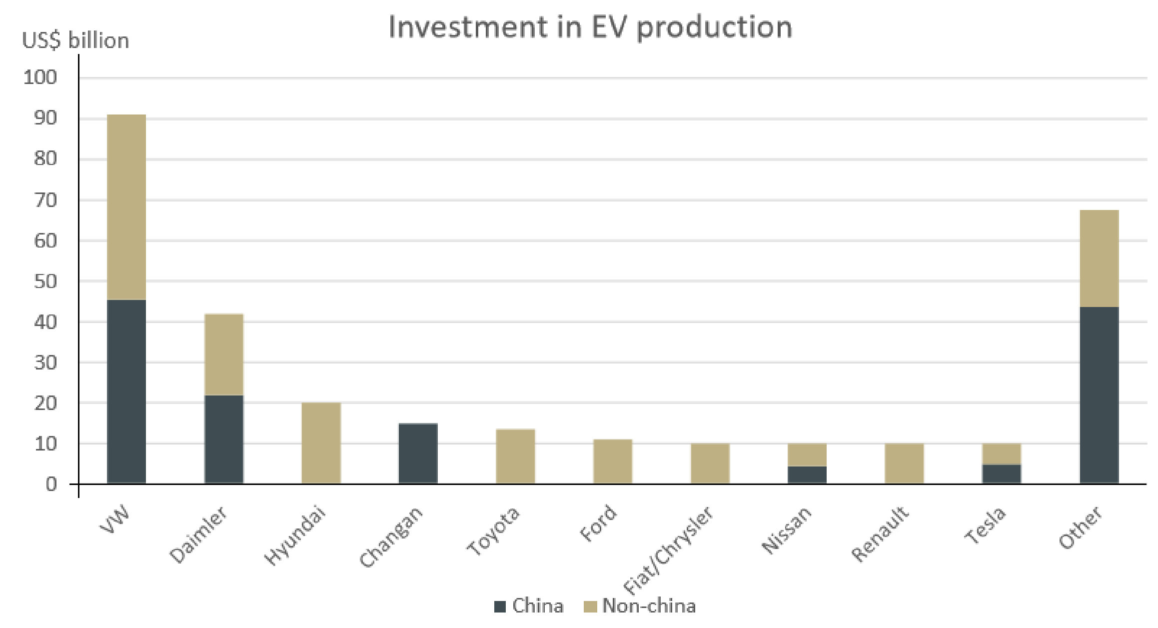


Source: UBS, 2020

Given the current year-on-year rate of increase in production, analysts predict demand will shortly outstrip supply due to the rate of growth. Even China, the big player in the game, is failing to meet the current demand, let alone meeting the future demands of this phenomenal change in lifestyles required by climate change mitigation. This is the time for Africa to position itself in readiness for its share of the cake. Africa's aim should be to add value to its REE ore deposits up to at least the separation stage and produce the metal as the final commodity. This will attract the manufacturers of EV parts or the auto makers to consider possible synergies or offtake agreements. News of the electric vehicle revolution is everywhere, with government targets being set to reduce the number of ICE vehicles on the road over the coming two decades, and the pledged investment in electrification by major automakers amounting to $300 billion to date. Figure 3 shows the breakdown of the significant investment pledged by the automakers.

The companies listed in Figure 3 should represent Africa's target companies to seek synergies and offtake agreements for its REE resources. There is much to gain in terms of developing the African value chain by collaborating with established customers of the commodity. Financially the companies can inject capital via offtake agreements to set the ball rolling for the development of the value chain, and technically they can provide the expert skill and knowledge to produce quality materials. Africa needs to rapidly achieve a level of competitiveness in the production of quality products and working with established organizations is the fastest way to achieve those goals.

FIGURE 3: Distribution of the planned $300Bn investment in electric vehicles (EV) by manufacturer.



Source: Reuters, 2019

Green Energy

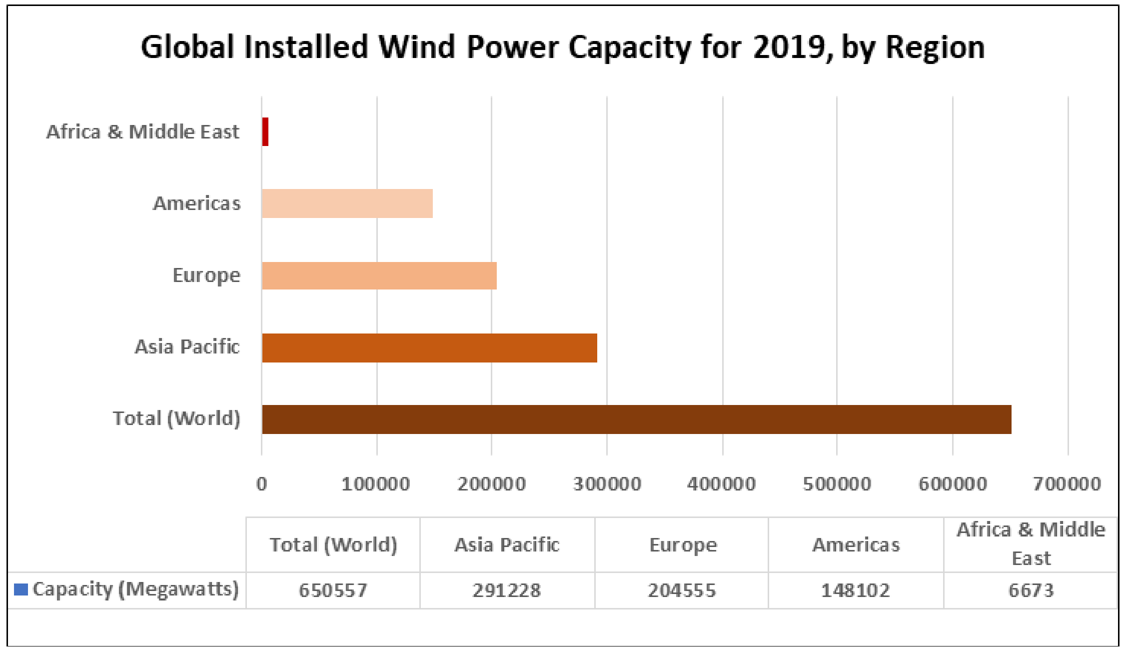
Green energy projects are a critical enabler for electric vehicles to reduce carbon . Electric cars run on batteries that are normally charged by electricity from national or regional grids. If the source of that grid electricity is fossil fuel, then effectively there is no carbon emission mitigation. This is equally true if the technology used to manufacture those batteries employs fossil fuel. This has led governments across the world to develop policies that accelerate the development of green energies to replace fossil fuel. One such technology for which REE is key, is wind power which requires about a tonne of REE for a 5MW direct drive turbine (Rainbow). The wind turbine market is expected to account for approximately 30% of the global growth in the use of REE magnets from 2020 to 2025.

Africa is at the start of its journey towards wind power, albeit at a slower pace than other continents. Data from Statista indicates Africa and the Middle East's installed capacity from wind power was close to 7GW in 2019 (Statista.

com), which is about 0.1% of the global capacity (Figure 4), and more than 95% of that capacity is in Africa. At the given consumption rate, Africa has already consumed at least 1,400t of REE in wind turbines from imports alone, against the backdrop of enormous REE resources.

Global wind power capacity additions are expected to reach an annual average of 77GW from 2020 to 2029, according to Wood Mackenzie[2]. This represents a growth of 112% in global installed capacity from the end of 2019 to the end of 2029. In terms of REE consumption, this equates to an average increase of 15,400t per year in wind turbines alone, which is a clear indication of robust growth in the global REE market.

FIGURE 4: Global installed wind power capacity in 2019, by region (in Megawatts)

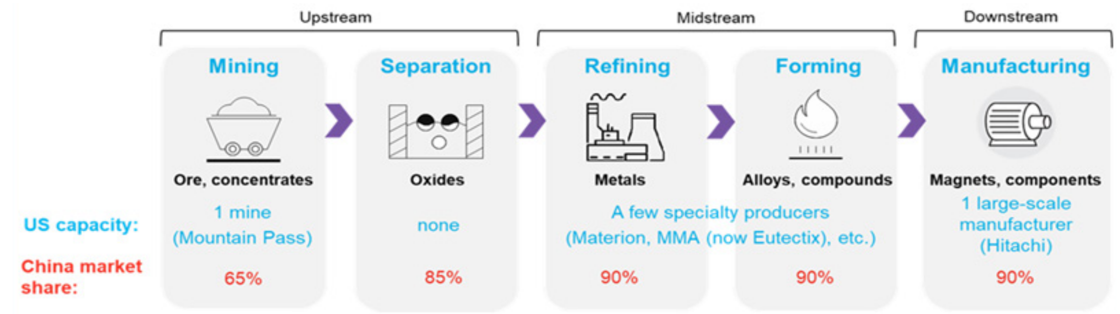


1.1 The REE Value Chain

It is logical to assume that once identified, a REE deposit of economic value will be exploited and progress along the beneficiation value chain to the market like any other metal commodity. This is however not the case with REE as the market is dominated by China, unlike other metal commodities, which are traded on open metals markets. This has made the REE value chain uniquely complicated. A thorough analysis of the dynamics controlling the REE market is important to any organization seeking to enter this space. As the value addition pipeline from exploration to mining to processing and marketing of the product is unusual, the risks associated with venturing into a market that is a monopoly are important to understand in order to mitigate risks. The end user market is known to exist across the developed world, but supply has remained in the grip of China making it difficult for new players to enter the market independently. Figure 5 shows the end-to-end dominance of China on the REE value chain, with market shares ranging from 65 - 90% from the upstream to the downstream end of the value chain.

[2] *https://www.woodmac.com/press-releases/global-wind-power-capacity-to-grow-by-112-over-next-10-years/#:~:text=Global%20wind%20power%20capacity%20additions,to%20the%20end%20of%20 2029.*

FIGURE 5: Rare earth minerals value chain showing the dominance of China.

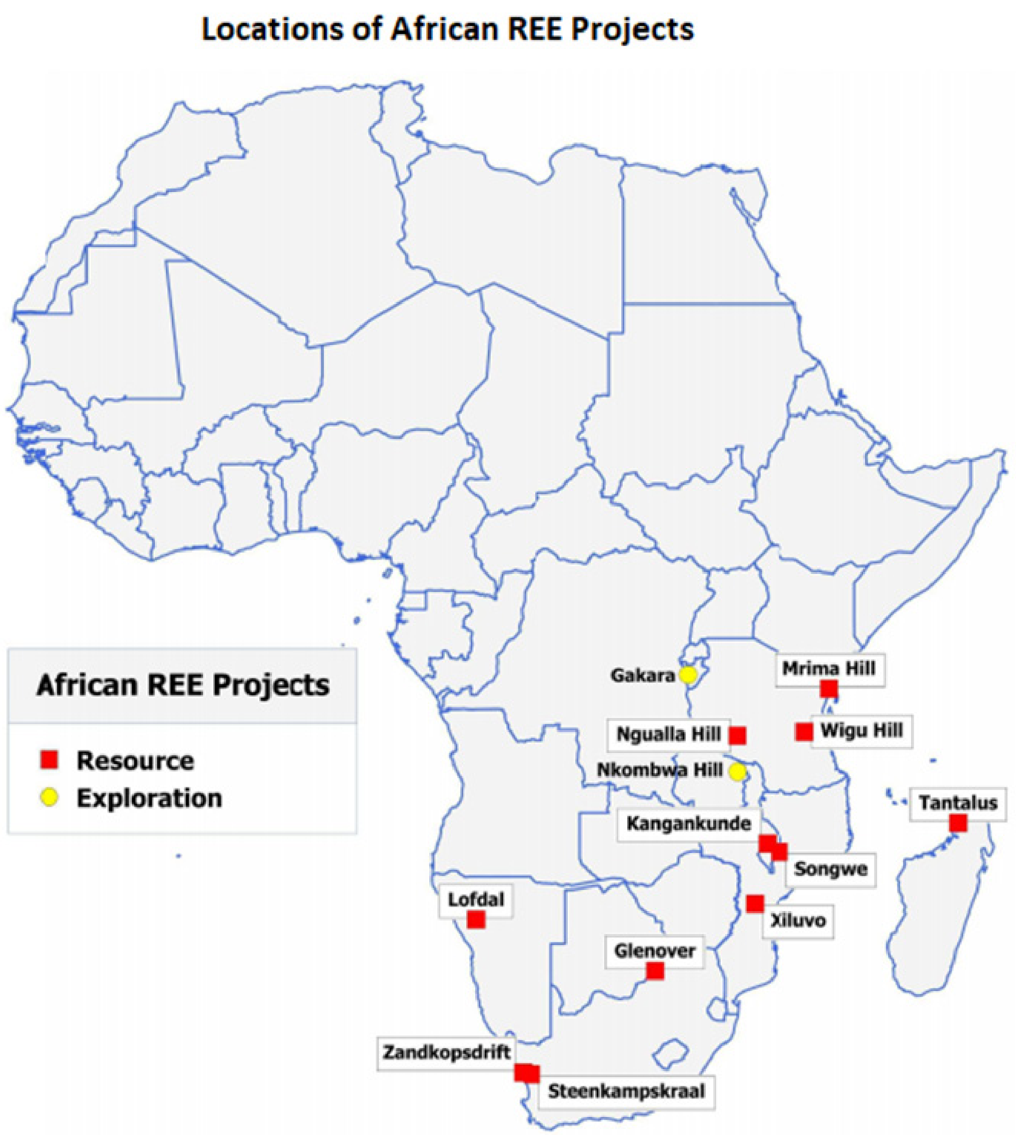


Many African states are experiencing rapid economic development and are conscious of the need to reduce carbon concentration in the atmosphere. The use of REE-bearing products is obviously on the increase but due to the lack of established REE value chains, Africa continues to rely on imports. This research therefore explores the opportunities Africa can tap into to develop the REE value chain and create a competitive edge over other players on the globe. Whilst significant reserves have been found in South Africa and Malawi, there are existing projects in several African countries that have identified significant resources, including those in Tanzania, Zambia, Namibia, Kenya, Burundi, Uganda, Angola and Mozambique. Figure 6 illustrates the locations of REE projects in 2016.

Despite this resource availability and potential, Africa has not yet taken full advantage of harnessing this opportunity. This study seeks to find answers to the fundamental question of how African countries can harness these resources to accelerate their sustainable development.

To date, only Rainbow Rare Earth (owners of the Gakara Mine) produces REE concentrate in Burundi for the export market, without any further processing, and therefore little value realization by the country from the mining operation. On the mid to downstream side of the value chain, two projects are in the pipeline – the Steencampskraal, and Frontier's 950,000t TREO Zandkopsdrift projects in South Africa, which plan to produce REE salts and separated Rare Earth Oxides (REO), respectively. On the consumption side, there is no known development on the manufacture of magnets or other REE consumer products, yet wind farms that consume multiple REE magnets continue to grow. The commissioning of Uganda's EV factory is imminent, with both developments having to import REE-bearing magnets and batteries for use, when Africa has abundant REE deposits.

FIGURE 6: Location of African REE Projects (2017)



Source: Source: R.Harmer et al.

The main policy that guides mineral extraction and development in Africa, the Africa Mining Vision (African Union, 2009) recognizes the importance of mineral value chains through the development of mineral "linkages." The Africa Mining Vision (AMV) envisages the "transparent, equitable and optimal exploitation of mineral resources to underpin broad-based sustainable growth and socio-economic development." This shared vision will require a knowledge-driven African mining sector that stimulates and contributes to the broad-based development of a single African market and becomes fully integrated in it. There is no doubt that the development of mineral value chains in African countries is considerably constrained by the individual subsisting national economic conditions, as well as international trade peculiarities and environments and that these factors affect the continent's collective ability to successfully leverage inherent comparative advantages. Entry barriers to highly essential downstream processing would provide one such example. Assessing these conditions, as well as related risks and rewards, ensures that with properly designed interventions, the deliverables are aligned to expectations. Based on this, it is therefore apparent that the need for downstream processing requires greater examination and understanding of these processes.

1.2 Objectives

The objective of the study is to assess the opportunities and challenges of harnessing the REE value chain to accelerate industrialization and broad-based sustainable development in Africa. The specific objectives are: (i) to assess the current and future status of REE reserves and their value chain in Africa; (ii) to identify opportunities and challenges for value addition in the REE value chain in Africa; and (iii) to propose options or policy incentives for promoting value addition, efficiency, and equity of the REE value chain in Africa.

1.3 Methodology

The methodology adopted for the research was a desk-based approach, supplemented by company consultations through online interviews. Based on the findings of the desk research, the management personnel of four companies currently developing rare earth projects in Africa, Steenkampskraal Holdings, ("SKKH"), Frontier Rare Earth Resources ("Frontier"), Rainbow Rare Earth Resources ("Rainbow") and Ionic Rare Earth were interviewed. The four companies provided additional data for the study. This assisted in making comparisons with REE projects in other parts of the world. Some of the issues considered included: (i) an analysis of drivers of REE demand, particularly REE products used in low carbon technologies, electronics, chemical engineering, and defence industries; (ii) an analysis of options to address the challenge of economies of scale including the possibility of regional cooperation; and (iii) an analysis of the upstream and downstream supply and demand scenarios to inform policy options for establishing REE value chains in Africa. Microsoft Excel was the main tool used for data analyses and drawing conclusions for the research.

Mineral Resource Development and Mining

Available geological and mining literature was collected from multiple sources and analyzed to understand the mode of REE mineralization in the various deposits across the world and their distribution, particularly in Africa. Minerals and mining data were analyzed, and comparisons made to draw analogies between the situation in Africa and the rest of the world. Mineral resource development data formed the basis for economic analysis of the industrial sector including market evolution, criticality of the metals and risk associated with their development.

Market Analysis

Literature collected from industry stakeholders and other sources was used to draw the baseline market economics of the REE industry, with a focus on Africa in the global market of REE products. The research assessed the supply and demand scenarios in a bid to determine likely availability of the resource on the upstream side and market availability on the downstream side and outline the environmental considerations necessary to develop the value chain. In the current state of development, the REE market is segmented into REE process products (concentrates, salts, oxides and metals) and REE consumer products (electronic, optical, magnetic, and catalytic applications). Drivers for developing the value chain are determined by assessing demand for consumer products, which, together with price forecasts, can be used in a top down approach to determine possible economic parameters of establishing the upstream and intermediate industry units of the value chain.

Consumption forecasts enable the likely REE demand in future to be determined, which then serves to advise governments of the industry growth rate needed if the industry is to stay at par with demand. Analyses of trends of relevant economic indicators such as population demographics, employment, literacy, gross domestic product, and energy consumption enables consumption forecasting and therefore REE demand in future. The research therefore advises on the likely growth trends for the industry based on these economic indicators. This will inform governments of the quantity of REE expected in future, which by backward integration, will indicate to industry the quantities of the REE intermediate industry and mining operation required to meet the demand.

In the event of Africa developing the REE value chain, its immediate global target market is China or the Western world. The research analysed the advantages and disadvantages of each market and the likely synergies the continent could consider developing a competitive edge in this industrial sector. Africa as a consumer is still trailing behind and unlikely to drive meaningful consumption and find a market large enough to support the economic viability of the industry. The research explores options that can transition Africa from being a net exporter of semi-processed products (or net importer of finished products) to being a producer and consumer at the same time.

Sustainability of the industry forms a key component of the research, which necessitated an investigation of the policy conditions which create an enabling environment, as well as providing advice on best practice that promotes investment in the industry. Consultations with industry stakeholders in South Africa, Tanzania and Burundi supported this evidence to draw analogies enabling the development of robust policies that support and promote a viable value chain.

The research took into consideration the fact that all the companies investing in Africa are foreign, listed on major stock markets (LSE, AIM, TSX, ASX). Whilst foreign direct investment (FDI) is important in the development of countries and regions in which companies invest, the study explored the possibility of developing local companies, owned by the citizens of the respective jurisdictions, and the benefits that comes with such investments. These scenarios were analysed at the policy level for the African continent, including the development of robust enabling policies and strategies. Consideration was made of how Africa-wide agreed cooperation on AfCFTA, the AMV, and the Geological Information Management Systems (GMIS) could be leveraged. This might include strategic regional approaches involving producer processor initiatives across countries and the African Mineral and Energy Management System (AMREC) aligning with the United Nations Framework for Mineral Classification (UNFC). This is with a view to have a robust 'home-grown' approach to benefit from these endowments across the mineral value chain. Research and Development (R&D), and trade protective legislation, both nationally and regionally activated, are discussed and offered in the study for REE value chain development.

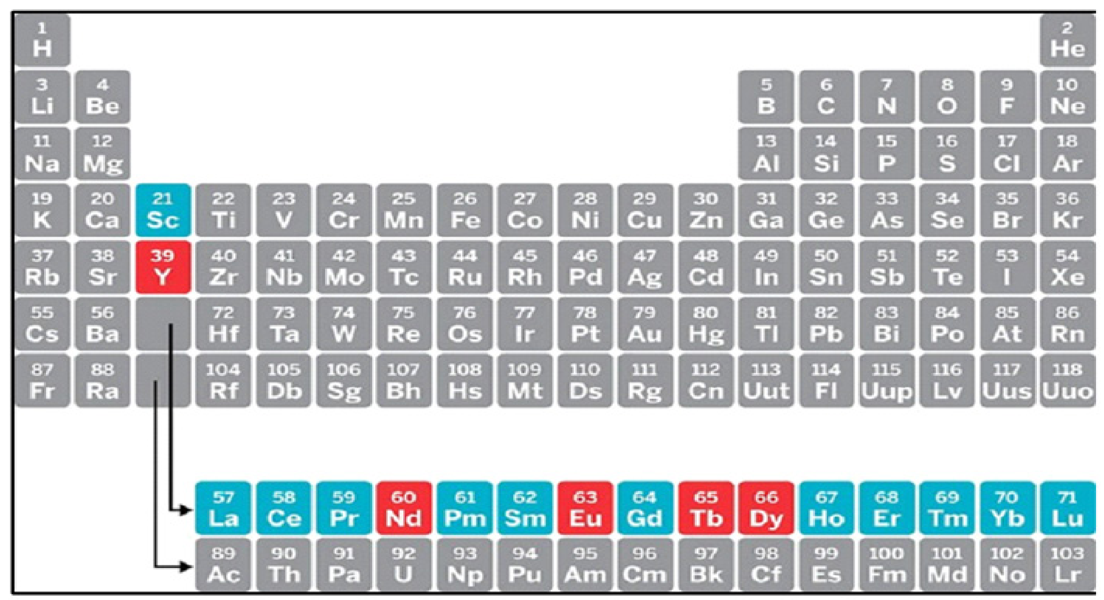
Finally, steps to increase competitiveness were highlighted, including the establishment of intra-regional production and trade of ores, and exploiting the advantage of South Africa's infrastructure and human capacity for the downstream side of the value chain development. The technology and skills requirements among AU member states, and current deficiencies along the REE value chain were also analysed, while identifying existing gaps and proposing remedial actions, and proposals made to drive optimum REE value chain development in Africa at national and regional levels.

02

Global and Continental REE Deposits

Rare Earth Elements (REE) are a group of 17 metals typically occurring together in natural geological environs. The suite of rare earths is split into two distinct sub-categories, the light rare earth elements (LREE) including scandium (Sc) and the elements between lanthanum (La) and samarium (Sm), and the heavy rare earth elements (HREE) including yttrium (Y) and the elements between europium (Eu) and lutetium (Lu). Generally, the HREE fetch higher prices than the LREE due to a higher market demand. The USA further classified five REE as Critical Rare Earth Oxides (CREO in their oxide form) because of their importance to the US economy. These are yttrium, europium, neodymium, terbium and dysprosium. The main economic minerals are monazite, bastnaesite and xenotime. Figure 7 shows the suite of REE on a periodic table.

Figure 7: The Periodic Table showing REE in blue and the CREO in red.



Source - American Chemical Society

2.1 Occurrence of REE

Rare earth elements occur in a broad range of igneous, sedimentary and metamorphic rocks. The concentration and distribution of REE in mineral deposits is influenced by rock formation and hydrothermal processes including enrichment in hydrothermal and magmatic fluids, separation into mineral phases and precipitation and subsequent redistribution and concentration through weathering and other surface processes. Environments in which REE are enriched can be broadly divided into two categories: primary deposits associated with igneous and hydrothermal processes; and secondary deposit concentration by sedimentary processes and weathering. Within these groups, the REE deposits can be further subdivided according to their genetic associations, mineralogy, and form of occurrence. It is therefore not easy to classify these REE deposits as their formation can be a mix of many processes. For instance, deposits associated with carbonatites can be divided into those directly associated with magmatic processes and crystallisation, but others can be a senior replacement type or residual, surface-weathering or a combination of these processes.

Carbonatites are the most REE-enriched group of igneous rocks; though even the most enriched igneous rocks require the action of one or more secondary processes to produce economically significant REE grades. Table 1 shows some of the global REE deposits and their classification.

TABLE 1: Classification of Rare Earth Element-Bearing Mineral Deposits

Deposit Association	Deposit Type	Example
Peralkaline igneous rocks	Magmatic (alkali-ultrabasic)	Lovozero, Russia
	Pegmatite dikes (alkali-ultrabasic)	Khibina Massif, Russia
	Pegmatite dikes (peralkaline)	Motzfeldt, Greenland
	Hydrothermal veins and stockworks	Lemhi Pass, Idaho
	Volcanic	Brockman, Western Australia
	Metasomatic-albitite	Miask, Russia
Carbonatites	Magmatic	Mountain Pass, California
	Dikes and dialational veins	Kangakunde Hill, Malawi
	Hydrothermal veins and stockworks	Gallinas Mtns., New Mexico
	Skarn	Saima, China
	Carbonate rock replacement	Bayan Obo, China
	Metasomatic-fenite	Magnet Cove, Arkansas
Iron oxide copper-gold	Magnetite-apatite replacement	Eagle Mountain, California
	Hematite-magnetite breccia	Olympic Dam, South Australia
Pegmatites	Abyssal (heavy rare earth elements)	Aldan, Russia
	Abyssal (light rare earth elements)	Five Mile, Ontario
	Muscovite (rare earth elements)	Spruce Pine, North Carolina
	Rare earth elements-allanite-monazite	South Platte, Colorado
	Rare earth elements-euxenite	Topsham, Maine
	Rare earth elements-gadolinite	Ytterby, Sweden
	Miarolitic-rare earth elements-topaz-beryl	Mount Antero, Colorado
	Miarolitic-rare earth elements-gadolinite-fergusonite	Wasau complex, Wisconsin

TABLE 1: Classification of Rare Earth Element-Bearing Mineral Deposits (Cont)

Pegmatites	Rare earth elements-allanite-monazite	South Platte, Colorado
	Rare earth elements-euxenite	Topsham, Maine
	Rare earth elements-gadolinite	Ytterby, Sweden
	Miarolitic-rare earth elements-topaz-beryl	Mount Antero, Colorado
	Miarolitic-rare earth elements-gadolinite-fergusonite	Wasau complex, Wisconsin
Porphyry molybdenum	Climax-type	Climax, Colorado
Metamorphic	Migmatized gneiss	Music Valley, California
	Uranium-rare earth elements skarn	Mary Kathleen, Queensland
Stratiform phosphate residual	Platform phosphorite	Southeast Idaho
	Carbonatite-associated	Mount Weld, Western Australia
	Granite-associated laterite	South China
	Baddeleyite bauxite	Poços de Caldas, Brazil
	Karst bauxite	Montenegro
Paleoplacer	Uraniferous pyritic quartz pebble conglomerate	Elliot Lake, Ontario
	Auriferous pyritic quartz pebble conglomerate	Witwatersrand, South Africa
Placer	Shoreline Ti-heavy mineral placer	Cooljarloo, Western Australia
	Tin stream placer	Malaysia

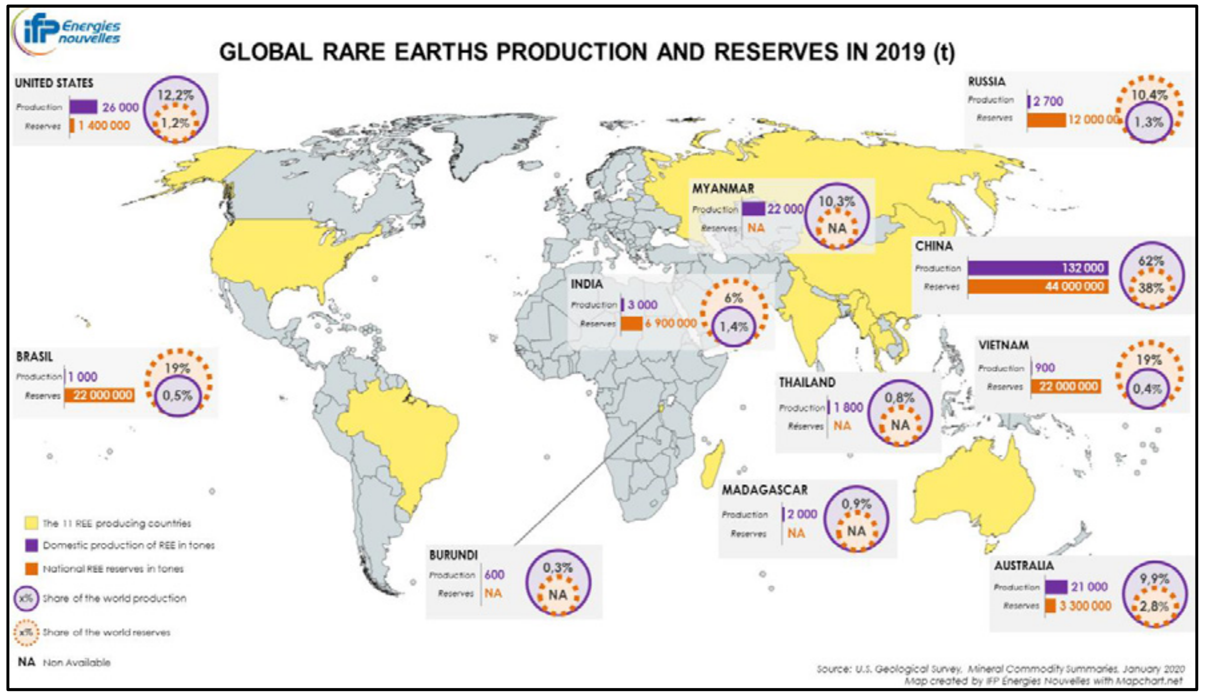
Source - WWW.Geology.com

2.2 REE Mineral Resources in Africa

Figure 8 shows the global distribution of known REE deposits. Rare earth element deposits in Africa are significant compared to other parts of the world, with highest number of deposit concentration in the southern and eastern parts of the continent.

Exploration generally dates to the first half of the twentieth century but most of the historical activity on mineral resource development was abandoned due to the lack of market at the time. This changed at the start of the 21st century, driven by the growth in the high-tech industry. Several deposits have been identified in Africa, with most of them being carbonatite type deposits in the south-eastern part of the continent. Table 2 shows a selection of some of the deposits discovered in Africa.

FIGURE 8: Global Rare Earth Deposits.



Source: iNEMI, 2019

TABLE 2: Selected REE projects in Africa

Country	Name	Type	Description
Burundi	Gakara	Carbonatite	**Karonge/Gakara** is the first REE mine in Africa with a historical production of 5,000t since 1936. The Gakara carbonatite vein system lying west of Burundi is approximately 20 km southeast of the capital Bujumbura and 12-14 km east of the shores of Lake Tanganyika. It started production in 2017 and is the only producing mine in Africa, 600t at 54 % REE in 2019 according to the US Geological Survey, even though the miner, Rainbow Rare Earth, has not yet declared the resource available.
Kenya	Mrima Hill	Carbonatite	**Mrima Hill** carbonatite cluster is about 60 km south-west of Mombasa and 10km from the coast of southern Kenya. The carbonatites agglomerate and fenitised sediments are Cretaceous in age. Economic grades of REE and niobium mineralisation are developed in the laterite capping produced by weathering of the igneous components of the hill. An REE resource of 48.7Mt at 4.40% TREO for 2.15Mt of contained REO, with a further 4Mt of contained REO in the inferred category, has been estimated.

TABLE 2: Selected REE projects in Africa (continued)

Madagascar	Tantalus project	Clay	**The Tantalus project**, which is located on the Ampasindava Peninsula is about 580km north of the capital, Antananarivo. The deposit is of the ion-adsorption-clay type and is unique amongst the REE projects in Africa. It occurs within the Ambohimirahavavy Alkaline Complex that is a member of the late Oligocene/early Miocene Ampasindava Alkali Province. A preliminary inferred resource was estimated for each of the five prospect sub-areas within the project using data from 277 boreholes and 1,000 pits (<10 m depth) It is estimated that over 550,000t of contained REO exist in the Tantalus Mineral Resource, including 40.1Mt of Measured Resource at a grade of 0.097%TREO for 52,200t of contained REO.
Malawi	Kangankunde	Carbonatite	**Kangankunde** carbonatite complex, is situated south of Lake Malawi, approximately 75km north of Blantyre. It is one of several carbonatitic complexes. REE mineralization is pervasive within the true carbonatites and extends outwards into the fenitised and carbonated units. An inferred resource, compliant with the Joint Ore Reserves Committee (JORC) of the Australian Institute of Geoscientists guidelines of 2.53Mt at an average grade of 4.24 % REO for 107,000t of contained REO has been estimated.
	Songwe	Carbonatite	**Songwe** carbonatite deposit is located south of Lake Chilwa, approximately 85 km east of Blantyre and close to the Malawi-Mozambique border. The vent cuts the western margin of the large Mauze nepheline syenite. An ore reserve of 8.5 Mt at a grade of 1.6% TREO for 136,000t of contained REO has been reported.
Mozambique	Xiluvo	Carbonatite	**Xiluvo** REE deposit lies within the Xiluvo carbonatite complex located in the Sofala Province, some 110 km inland of the port of Beira. Sampling of the Xiluvo carbonatites showed moderate REE concentrations in the calcitic intrusives with about <0.8 %TREO, and higher concentrations of up to 2% TREO sporadically developed in the tuffisitic phase. The exploration has shown limited resource of the deposit.
Namibia	Lofdal	Carbonatite	**Lofdal** REE project is located in Kunene Region, north-west Namibia, approximately 26 km west of the town of Khorixas. It covers a total area of around 200 km^2. It is rich in the HREE elements relative to the LREE. A resource estimate of about 2.98Mt of indicated resource with a grade of 0.32 %TREO for 9,220t of contained REO, plus a further 8,860t of REO at inferred stage has been calculated.
South Africa	Zandkopsdrift	Carbonatite Vein	**Zandkopsdrift** deposit lies close to the Atlantic coast in the south of the Northern Cape Province of South Africa. The Zandkopsdrift carbonatite is located within the bounds of the Cretaceous-aged Koegel Fontein Complex. The majority of the REE-bearing minerals consist of late-stage, supergene members of the monazite group; along with apatite-derived REE phosphate phases. Total Reserves amount to 41.12Mt at a grade of 2.30% TREO for 950,000t.
	Steenkampskraal	Vein	**Steenkampskraa**l deposit located in the north-western part of the Western Cape Province of South Africa, approximately 350 km north of Cape Town. The Steenkampskraal deposit is hosted within Mesoproterozoic granitoid gneisses near the southern edge of exposure of the Namaqua Province. A total REE resource for the project of 605,000t at an average grade of 14.4 % TREO for 87,000t of contained REO has been declared for the deposit.

TABLE 2: Selected REE projects in Africa (continued)

	Glenover REE- Phos	Pyroxinite/Carbonatite/ Sediment	**The Glenover REE-Phosphate** is located in the Lephalale district of north-western Limpopo Province. It is composed of a 3.5 x 4.5 km sized plug-like intrusion of micaceous pyroxenite and carbonatite, and sediments of the Waterberg Group. REE and phosphate mineralization is hosted in a body of iron oxide-rich apatite-calcite breccia developed at the contact between a major body of carbonatite and pyroxenite near the centre of the complex. A total of 221,000t of contained REO remain in unmined *in situ* breccia ore, and on the stockpiles.
Uganda	Makuutu	ionic clay-type	**Makuutu** geology is similar to the ionic clay-type deposits of southern China where the world's cheapest and most readily accessible sources of Heavy Rare Earth Oxides (HREO) are extracted by rudimentary mining and processing. It comprises of three licences covering approximately 132 km^2 located some 40 km east of the regional centre of Jinja and 120 km east of the capital city of Kampala. Typically, rare earths can be recovered from ionic clay mineralisation using mild salt washing/leaching conditions to produce a high-grade REO chemical precipitate concentrate and generally present practical processing advantages. Drilling has so far delineated an inferred mineral resource of 47.3Mt at 910ppm TREO (or 610ppm less (Ce_2O_3).
Tanzania	Wigu Hill	Carbonatite	**Wigu Hill occurrence** is approximately 250 km west of Dar es Salaam and about 10 km north of Kisaki village. Two varieties of carbonatite are recognised: medium-grained dolomitic carbonatites and coarse-grained calcite carbonatites, both of which may be locally brecciated. REE mineralized sheets occur as pegmatoidal rock and a finer-grained, streaky to foliated variety of fine-grained, anhedral REE minerals set in a granular matrix of ferroan dolomite. The highest assay value obtained on kilogram-scale outcrop exploration grab samples is 26.2 % TREO. Ten target areas of REE mineralization are known with a revised inferred resource of 1.93 million tonnes at 2.69% TREO for 51,917t of contained REO.
	Ngualla Hill	Carbonatite	**Ngualla Hill REE** deposit in Tanzania, near Mbeya in southwest Tanzania is centred on the Proterozoic Ngualla Hill carbonatite complex which lies within the western limb of the East Africa Rift System. REE concentrations in the calcite carbonatite are generally less than 0.25 % TREO and are held in monazite. The REE resource at cut-off grades of 1% and 3% TREO yielded resource grades of 2.26% and 4.19 % TREO respectively. While the high-grade option represents only 22% of the total resource, it is sufficient for a project life of more than 50 years at current conventional processing rates.
Zambia	Nkombwa Hill	Carbonatite	N**kombwa Hill** is located in the Muchinga Province of north-eastern Zambia, is approximately 1.5 x 1.0 km in size. The pegmatoidal, vari-textured carbonatites have consistently elevated REE contents. Kilogram-scale outcrop rock chip samples frequently returned grades of over 10% with the highest individual sample value being 23.6% TREO from the pegmatoidal carbonatite and 22.3% TREO in the silicified unit. Phosphate concentrations are also elevated in the pegmatoidal carbonatite- the most enriched sample contained 33.3% P_2O_5. No resource has yet been defined on Nkombwa.

Source: Rare Earth Deposits of Africa

2.3 Summary

Most of the mineral resource projects in Africa are at the preliminary stage but undoubtedly there is sufficient resources to warrant their further development (as shown in Table 2). Potentially a total of four million tonnes of contained REO are available in the projects listed. From a regional geological point of view, the current discoveries are only the tip of the iceberg. Similar geological formations on the continent, with potential for further discoveries, are yet to be explored. For example, numerous carbonatites like the discovered ones are known to exist along the East African Rift Valley. Grab samples in some of the carbonatites and associated fenites in the eastern limb of the Rift Valley in Uganda have consistently retained economic grades that warrant further exploration. The main obstacle is the strategic intent to enter the market, hence the need for market and value chain analysis.

While REE have similar chemical properties, there are higher concentrations of LREE, particularly lanthanum and cerium, than those of HREE in the earth's crust and deposits. HREE generally have a higher market demand than LREE, resulting in pricing variations, with HREE generally fetching higher prices than LREE. The difference in pricing can be so large that it can significantly impact the economics of a REE mineral development project. It is therefore important that individual REE metal evaluations are re-iterated during resource development to ensure the viability of the project.

The three most important REE minerals are bastnaesite, monazite and xenotime. Generally, bastnaesite contain the highest LREE and xenotime contain the highest HREE, with monazite leaning in between. The type of mineralization in a deposit is therefore significant as it can provide an indication of the likely profitability of the resource.

Whilst monazite leans towards the HREE in composition and therefore can contain the more valuable HREE, it frequently also contains the radioactive thorium, which can have serious health risks for the workforce and requires the radioactivity to be safely managed.

Most mineral deposits in Africa are carbonatites, with discoveries mainly concentrated in southern and eastern Africa. The potential for more deposit discoveries is high, particularly along the East African Rift system which is associated with carbonatite and other alkali magmatic intrusions. Regionally, these are target areas for new project discoveries.

Although many of the projects in Africa are still at infancy, indications are the deposits have mineral resources ranging from as low as 100,000t TREO to as high as 1 million TREO content. Estimating deposit sizes is critical, as the scale and likely profitability determine the strategy for developing the resource. One strategy is for smaller deposits to be clustered together in-country or in Regional Member States (RMS) for shared infrastructure development, and the large deposits to be developed as standalone projects, depending on the economies of scale.

03

REE Market Analysis

Chapter 3 therefore provides the market analysis showing the demand and supply constraints of REE and how they can be addressed.

In order to develop an REE value chain, the industry's market dynamics should be well understood. In such an analysis, there are two fundamental questions to be answered: 1) Is there a market for the commodity? and 2) if the market is available, is there a supply source for the commodity? An affirmative answer to both questions creates the environment for establishing value chain development. Analyzing the economic dynamics of the industry, together with the logistical capabilities of establishing such a supply chain, would then determine the tilt of the balance as an opportunity for entry into the REE supply system and downstream consumer industry development. This section therefore investigates both ends of the value chain to determine the position Africa can take to participate in this growing industrial sector. Two main factors have been at the forefront of REE demand: 1) the Chinese risk factor; and 2) advances in high-tech products, particularly the technologies for a low carbon future.

3.1 Supply Side Analysis

The world is endowed with many REE deposits as shown in Figure 8 above, but China is the dominant player in the industry as depicted in Table 3, showing world REE reserves and production figures for years 2018 and 2019.

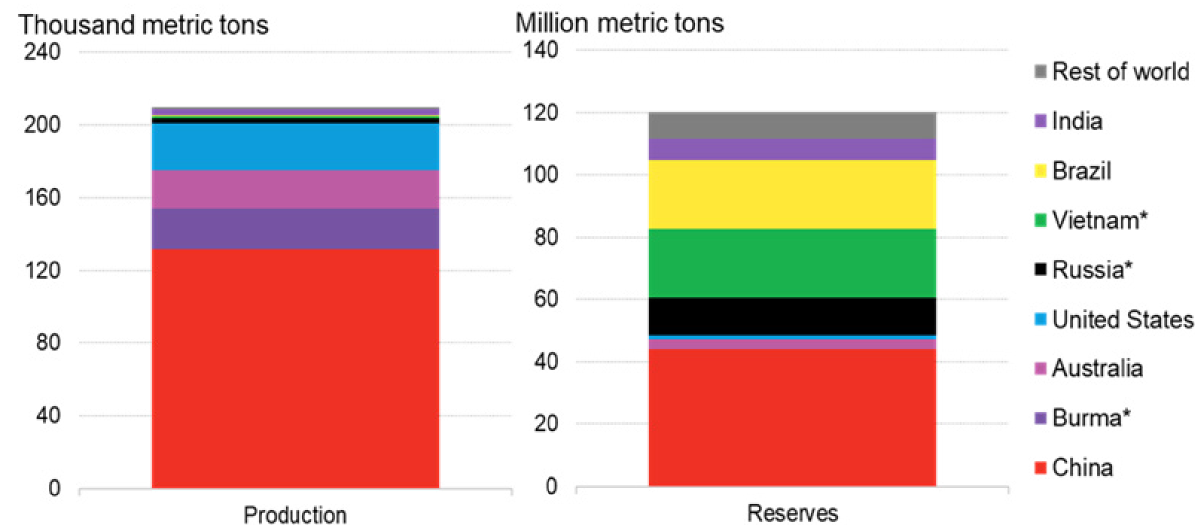
In terms of reserves, China has the largest known REE reserve in the world (38%), and according to USGS production figures of 2019, China produced 132,000t of Rare Earth Oxides (REO) out of a total global production of 210,000 REO (Table 3), which is equivalent to 61.97% of the world's production (70.59% in 2018). This dominance of China on the supply side of the value chain can be clearly demonstrated graphically as shown in Figure 9.

TABLE 3: World REE country reserves and 2018-2019 REE production.

Country	REE Reserves (X1,000T)	REE Reserve (%)	Mine Production (T)		2019 Production (%)	Change in Production (T)	Change in Production (%)
			2018	2019			
China	44000	37.82	120000	132000	61.97	12000	10
Brazil	22000	18.91	1100	1000	0.47	-100	-9.09
Vietnam	22000	18.91	900	900	0.42	0	0
Russia	12000	10.32	2700	2700	1.27	0	0
India	6900	5.93	2900	3000	1.41	100	3.45
Australia	3300	2.84	21000	21000	9.86	0	0
Greenland	1500	1.29	0	0	0	0	0
USA	1400	1.2	18000	26000	12.21	8000	44.44
South Africa	1050	0.90	0	0	0	0	0
Tanzania	890	0.77	0	0	0	0	0
Canada	830	0.71	0	0	0	0	0
Others	310	0.27	0	0	0	0	0
Burundi	150	0.13	630	600	0.28	-30	-4.76
Myanmar	NA	NA	19000	22000	10.33	3000	15.79
Madagascar	NA	NA	2000	0	0	0	0
Thailand	NA	NA	1800	1800	0.85	0	0
Total Global	**116330**	**100**	**190030**	**213000**	**100**	**22970**	**12.09**
Total Africa	**2,090**	**1.8**	**630**	**600**	**0.28**	**-30**	**-4.76**

Source - USGS

FIGURE 9: Global REE production and reserves, 2019.



Source - BNEF.

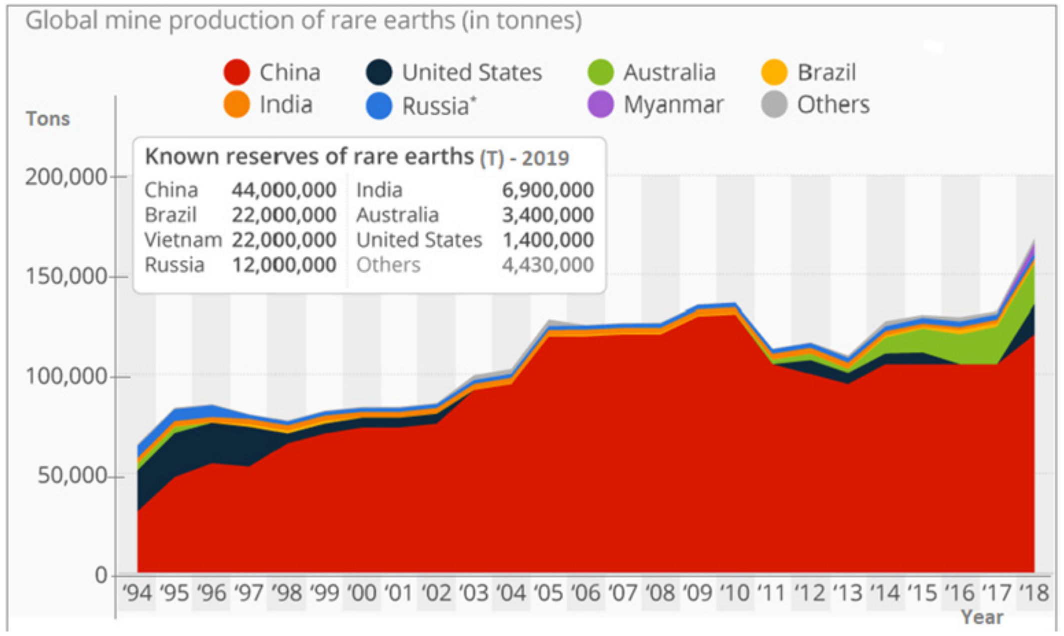
Both Table 3 and Figure 9 illustrate the key players on the upstream side and their relative share of the global REE supply chain. It is apparent that China has a near monopoly on the upstream side of the REE supply chain. Other countries with significant reserves are Brazil, Russia and Vietnam, collectively constituting almost 50% of the known mineral reserves. Africa's 2.09 million tonne reserve contributed 1.8% to the world's REE reserve; the 600t production, equivalent to 0.28% of world production were all from the newly commissioned Gakara Mine in Burundi. It is important to note the discrepancy between the data for Africa from USGS to the data obtained independently from the project developers themselves. For example, Table 3 indicates combined REE reserve of 2,090,000t (1.8% of the world's total reserve including a crude estimate of 150,000t for the Gakara mine), with South Africa shown as having a total of 1,050,000t, but figures obtained independently from Frontier and SKKH sums up to almost 900,000t as the total mineral reserve in South Africa. A possible explanation could be that commercial in-house data is not yet available on the public domain, hence the discrepancy.

On the mine production side, it is important to note the significant difference in production between 2018 and 2019, where, in absolute terms China reported the highest tonnage increase in production of 12,000t followed by the USA with an increase of 8,000t. However, when expressed in relative terms, the USA increased its production by a massive 44% against China's 10%. The increase is reflective of the increased demand in REE raw material, but is also a clear indication that other countries are stepping up competition with China. Against the backdrop of the world mineral reserve, we have already seen China's production falling from 70.59% to 61.97% of the total world production in 2018 and 2019, a drop of 8.62% in a year. Going forward we are likely to see the 8.62% market clawback increasing significant as the other major consumers of the commodity, particularly the developed countries, secure alternative REE supplies outside China's jurisdiction. Australia, Myanmar and the USA already have significant shares of the upstream market with a combined production of more than 30% of the world production in 2019. It is encouraging to see that Africa has also joined the market, with Rainbow Rare Earth developing and mining the Gakara deposit in Burundi (Table 3) following a ten year off-take agreement with Thyssenkrupp (TK) Materials of Germany.

3.2 China Risk factor

China has been the dominant player in the REE industry for the past 25 years for both the supply side (as shown in Figure 10) and the demand side, controlling up to 90% of the world's REE market, and owning almost half the world's known REE reserves. It is because of this dominance that China has strengthened its grip on the market which presents an enormous hurdle for other countries to compete without being affected by China's policies or influence.

Figure 10: Global rare earths reserves, and production dominated by China (shown in red).



Source: Statista, 2019

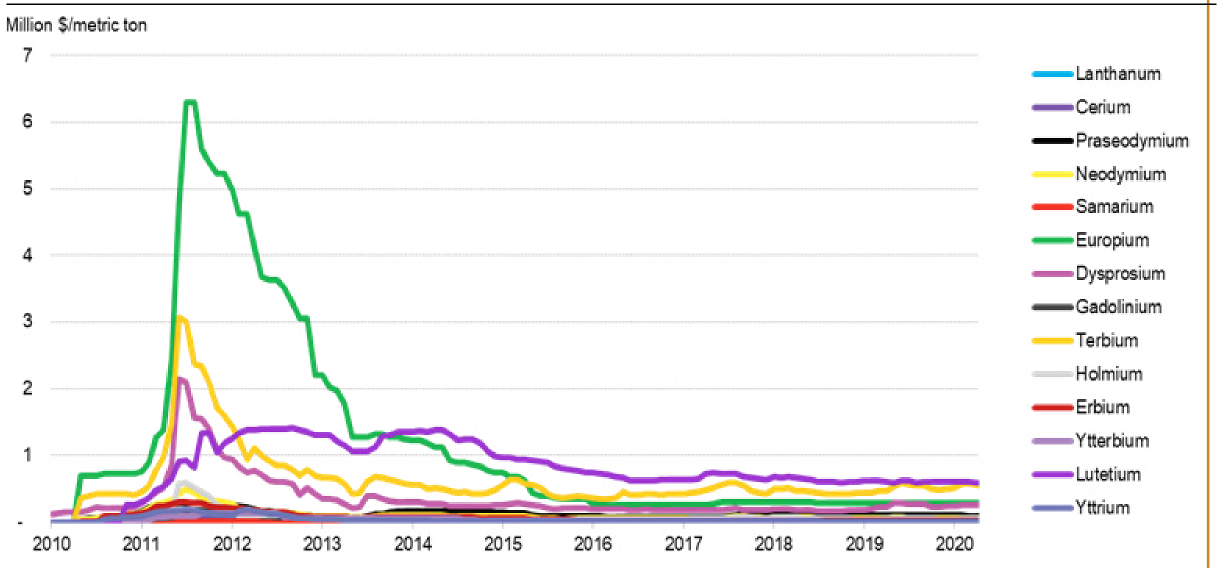
For many countries, particularly the more developed ones, the dominance of China in the REE business poses high risk in the supply of raw material for their high-tech industries. More recently, China's grip on the market is gradually loosening as non-Chinese companies have been entering the market from 2011 as shown in Figure 10.

The major question would therefore be why the other REE consumer countries would want to seek alternative markets when China has a huge mineral reserve and the capacity to meet world demand in the foreseeable future? The answer lies with China's policies on the REE market. China sought to boost its REE downstream manufacturing industry, and to promote its 'buy Chinese products" policy, and therefore imposed rare earths quota limits on production and on Rare Earth Oxide (REO) exports. This policy resulted in China's rare earth exports in 2010 decreasing by 40%, from 50,000t a year to about 30,000 tons. Export quotas were cut again by a further 20% in 2011, as China wanted to ensure sufficient supply for its own technological and economic needs. The 40% reduction in quotas in 2010 caused a severe rare earths supply shortage which effectively created a price spike. It also motivated manufacturers to relocate to China in order to guarantee their REE supply chain, which was an advantage from China's viewpoint.

On the other hand, China's imposition of quota limits on production and exports was perceived as high risk by major economies like the European Union, the USA, Japan, Australia and Canada, as some believed China could manipulate the policy for political purposes.

China temporarily cut off supplies to Japan in 2010, widely believed to be a result of a dispute that escalated from the use of territorial sea waters between the two countries, and an action which seriously disrupted the supply chain for major manufacturers like Toyota and Panasonic. In 2019, China threatened to cut off REE supplies to the USA as the trade war between the two countries escalated. Most countries perceive China's export policy on REE and its persistent threats to halt supply as a high risk in the development of high tech industries, defense technologies and mitigation of carbon footprint to the extent that many developed countries are being forced to seek alternative supply sources. To demonstrate the severity of the reduction in quotas in 2010/2011, Figure 11 shows REE prices from 2010 to 2020, which spiked during this period, some increasing by more than 400%.

FIGURE 11: REE price spike due to introduction of export quotas in 2010/11.



Source: Bloomberg NEF, 2020

In response to the price spike, junior mining companies entered the supply chain hoping to lock in on a market that suddenly became lucrative. Exploration projects mushroomed globally, including in Africa. This surge was however short-lived as new illegal REE supply from China came onto the market encouraged by high prices; and new supply from Lynas Corporation's Mount Weld mine in Australia and other producers elsewhere helped the market to re-balance. With China's announcement of the new quota in 2013, which was much higher than the market price at that time, REE prices crashed resulting in uncertainty in the future of the REE market. Investors withdrew their money from the market forcing most of the new junior mining companies into liquidation. It was only after the 2014 intervention of the World Trade Organisation to halt China's trade quotas, that prices started to stabilize, but most of the junior producers had already succumbed to the economic downturn. Only a few, like Lynas, survived and continue producing for the market outside of China.

Even though the REE value chain outside China did not fully develop after 2010, the key countries driving the world economy continue to perceive China's dominance in the industry a threat to the stability of their REE market supply. A raft of strategies has been put in place aimed at bolstering the development of the value chain independent of China. The following are some of the consequences of China's policies and the strategies implemented or being implemented by western countries to mitigate their supply risk:

2010 – The U.S. Department of Energy reported a possible shortage of five rare earth elements (dysprosium, neodymium, terbium, europium and yttrium), now commonly known as critical rare earth elements (CREE) or CREO in their oxide form (U.S. Department of Energy's report "Critical Materials Strategy (CMS)"). The uses for the critical rare earth elements are spread across magnets, batteries and phosphors.

2010 – The Rare Earth Supply Technology and Resources Transformation Act of 2010 was passed in the USA. The legislation's goal was stated in the same CMS report (page 133): - "To provide for the re-establishment of a domestic rare earth materials production and supply industry in the United States and for other purposes."

2010-11 – Rare earths prices spike as the Chinese export quotas take effect. Prices quadrupled in 2010, then doubled again over a 4-month period in 2011. 2014-15 – In 2014 the WTO ruled against China, which led China to drop the export quotas in 2015.

2019 – Chinese newspapers talked of a possible China retaliation to US tariffs on Chinese goods. This effectively forced the United States not to impose tariffs on rare earths and other critical minerals from China, a clear indication that REE supply took centre stage as the trade war between China and USA escalated. The USA's foreign policy was compromised as a result.

May 2019 – The Pentagon sought funds to boost U.S. rare-earth production as fears over China supply mounted. REE's use in military defence technology makes REE strategically important for the US's security, and continuing to rely on China for these strategic metals posed a high risk to the USA.

June 2019 – The Rare Earths Industry Association was launched in Brussels. The group has 12 founding members from nations such as the UK, Germany, France, the Netherlands, Japan and China. A key goal of the group is supporting transparency across the supply chain. Many countries would prefer the REE to be traded on open markets in metal exchanges like other metal commodities, than confined to China's 'monopoly' market.

June 2019 – Chinese rare earth prices soar with their potential role in the trade war.

2018 - 2020 – It is no secret that western countries are exploring options for alternative REE supply from sources in Africa: for example, the US is negotiating with Mkango Resources in Malawi through Talaxis. The big question is one of strategy where the western countries would prefer investing in African deposits through junior miners domiciled in their own jurisdictions, whereas a home grown end-to-end value chain could be more beneficial to the African nations. Most juniors developing REE in Africa have developed synergies with potential customers from the western world, albeit with stiff competition from China, which is also investing in some of the known deposits in Africa and has already established strong ties with many African states.

The European Union is also shifting towards Africa for its REE requirements to satisfy its green energy and low carbon future investment requirements. EBRD, EU's development bank, is planning to include Africa in its geographical scope of work for mining investment.

Regardless of whether China can continue driving the REE supply chain, the fundamental demand is ultimately driven by market economics which lies within the ever-growing high-tech industries and consumer population. For major REE consumer countries, China's monopoly on the REE end-to-end business is sufficient reason to promote the development of the value chain elsewhere outside of China. This is the opportunity Africa can tap into to establish its own home-grown value chain with a possibility for a wider market for its products.

3.3 Demand Side Analysis - REE Demand in High-tech products

High-tech consumer products requiring the use of REE continue to upgrade old technologies and at the same time countries are compelled to continue reducing their carbon footprint, which requires REE as major components for green technologies. Rare earths are required for modern high technologies like electronics, green energies, carbon footprint reduction, media and communications, and defence. They are the backbone of many of the devices we use daily, as well as the technologies that are necessary to preserve the earth's environment. Their importance in these high-tech industries is primarily because of their specific optical, magnetic and catalytic properties, which make them irreplaceable in a variety of applications (Table 4).

TABLE 4: Uses of REE likely to keep prices buoyant in the future.

APPLICATION	RARE EARTH	DEMAND DRIVERS
Magnets	Nd, Pr, Sm, Dy	Automotive, wind turbines, drives for computers, mobile phones, mp3 players, cameras, voice coil motors, hybrid and electric vehicles, cordless power tools, sensors, medical imaging (MRIs).
Nickel Metal Hydride Batteries	La, Ce, Pr, Nd	Hydrogen absorption alloys for re-chargeable batteries.
Phosphors	Eu, Y, Tb, La, Dy, Ce,Pr, Gd	LCD (Liquid Crystal Display), PDP (Plasma Display Panel), LED (Light Emitting Diode), energy efficient fluorescent lights/lamps.
Fluid Cracking Catalysts	La, Ce, Pr, Nd	Petroleum production – greater consumption by 'heavy' oils and tar sands.
Polishing Powder	Ce, La, Nd	Mechano-chemical polishing powders for tvs, monitors, tablets, mirrors and (in nano-particulate form) silicon chips.
Auto Catalysts	Ce, La, Nd	Tighter NO_x and SO_2 standards– platinum is re-cycled, but for rare earths it is not economic.
Glass Additive	Ce, La, Nd, Er	Cerium cuts down transmission of UV light. La increases glass refractive index for digital camera lens.
Fibre Optics	Er, Y, Tb, Eu	Signal amplification.

Source: Rainbow Rare Earth Company

Note: Scandium (Sc),Yttrium (Y), Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Lutetium (Lu), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb).

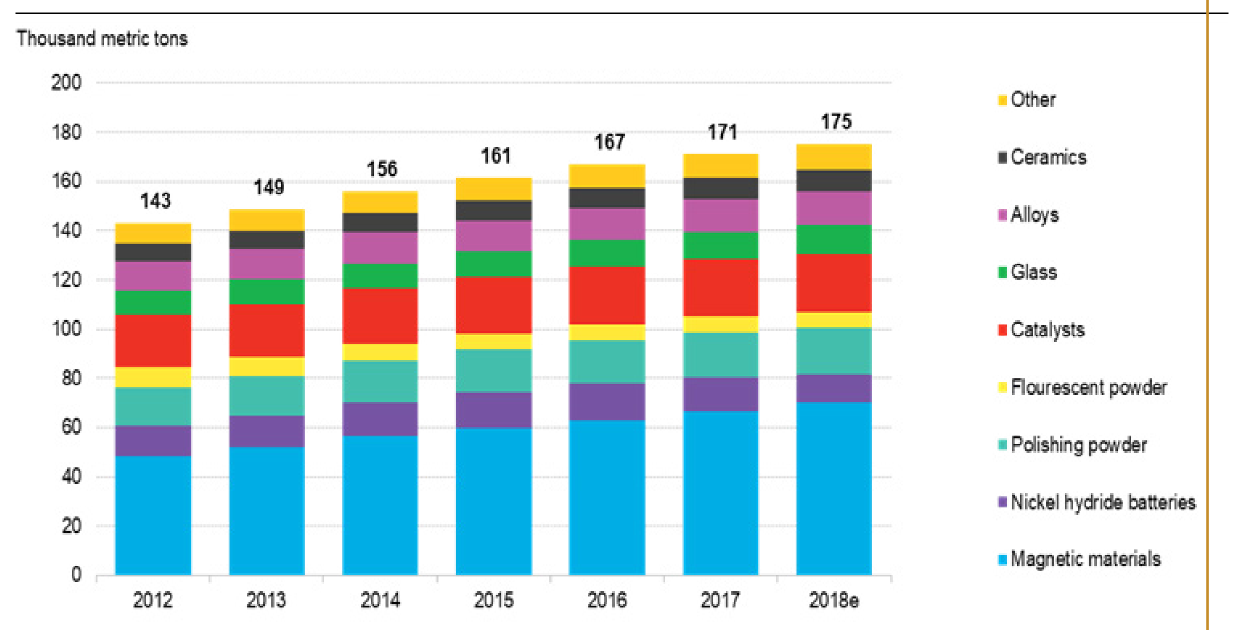
The key drivers of demand for REE include:

- The growth in technological progress and innovation;
- Environmental protection and climate change;
- Pollution and health;
- Energy security and energy efficiency;
- Defence.

REE are therefore shaping the future trends of industrial development based on increasingly low carbon emissions. Africa's drive towards a low carbon future will also be driven largely by the availability, utilization, and management of this group of metals which have become important raw materials in the new age of rapid technological advancement. For example, twenty years ago, there were very few cell phones in use, but the number has risen to over 7 billion globally and close to 600 million in use in Africa today. The use of rare earth elements also in computers has grown almost as fast. Many vehicles use rare earth catalysts in their exhaust systems for air pollution control. These examples are indicative of how the high-tech industry is growing and with it the demand for the raw materials including REE. Figure 12 below shows global REE demand for various applications from 2012 to 2018.

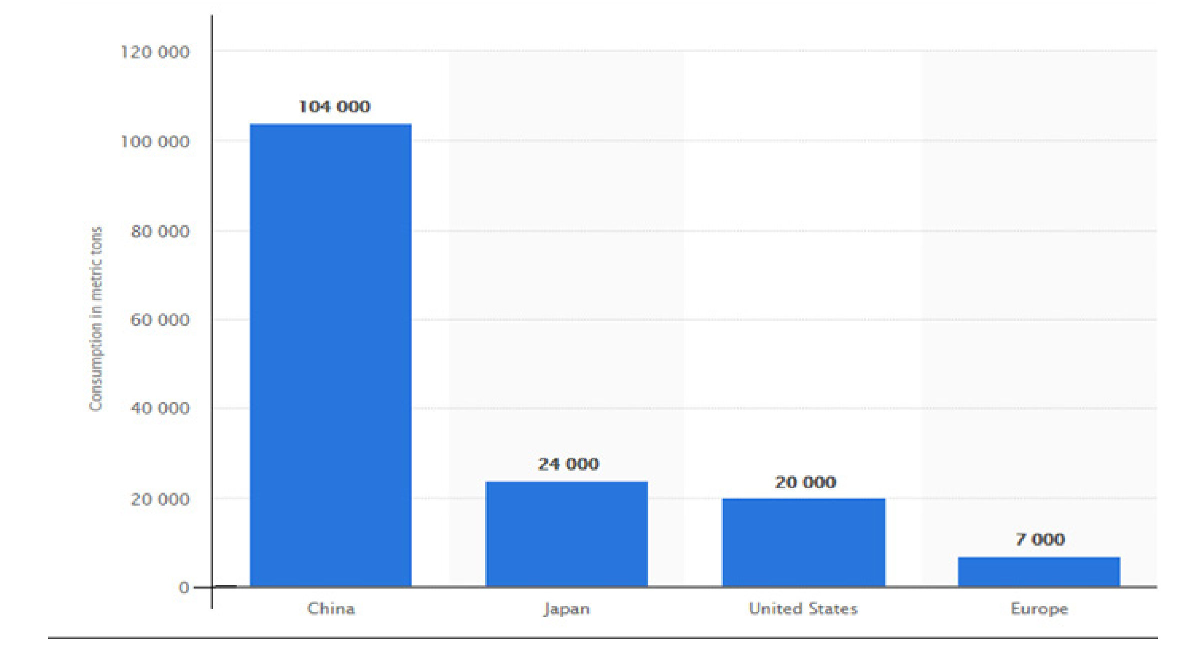
Rare earth demand is also heavily centred in the Chinese market, with China accounting for 65 - 70% of total rare earth demand as far back as 2015 (Figure 13). This is because China had a strategy to bolster its employment rate by developing a manufacturing industry with global proportions; and today, almost every household around the globe uses a Chinese manufactured product. Thirty years ago, China was a net importer of REE but developed the value chain systematically until it held a monopoly in the sector.

FIGURE 12: Global REE demand for various applications



Source:BloombergNEF, 2020.

FIGURE 13: Rare earth element consumption worldwide in 2016.

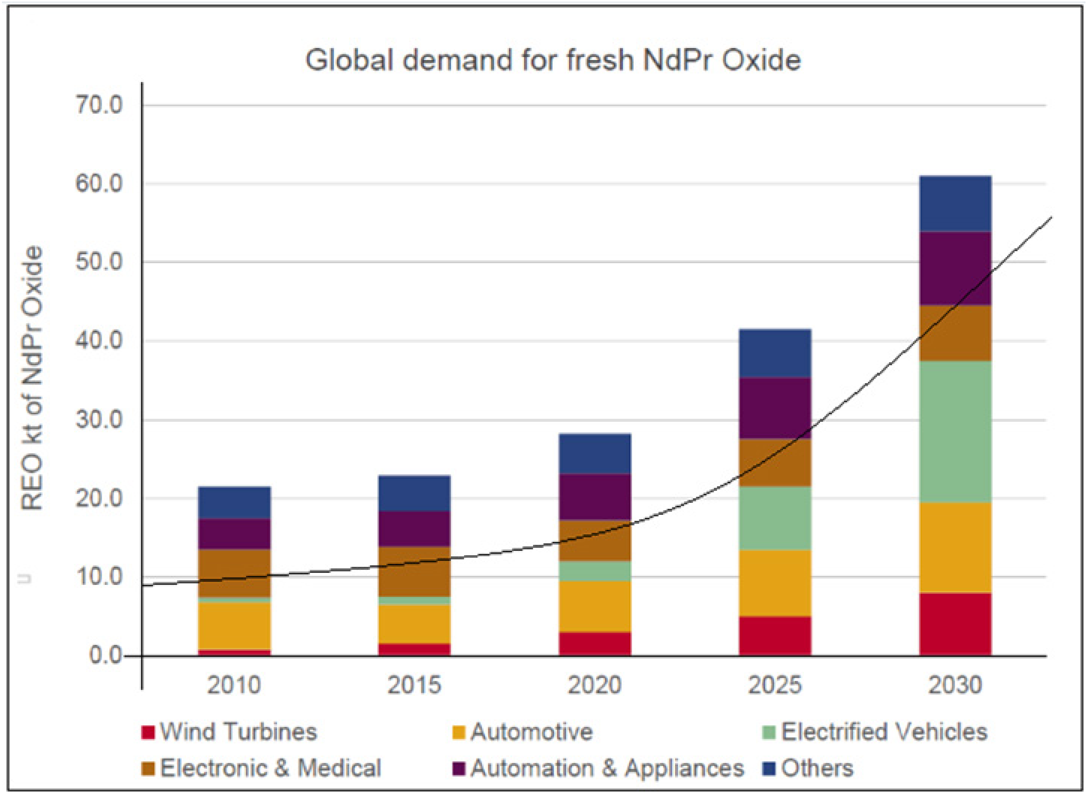


Source: Statista, 2020

When investing in REE, it is important to understand the economic dynamics of each of the 17 elements. Forecasting demand as a group may not provide the granular information necessary for decisions about whether to invest in the industry. Demand for REE comes from a variety of niche applications, each of which determine the forecasting of the individual elements. An example comes from the neodymium-praseodymium (NdPr) metals for high strength permanent magnets. Since the early 2010s, demand for rare earths used in these magnet applications has seen strong growth for compounds of neodymium (Nd) and praseodymium (Pr), which are used ultimately in the production of neodymium-iron-boron (NdFeB) permanent magnets. Other rare earth elements, principally dysprosium (Dy) and terbium (Tb) may also be introduced to NdFeB magnet alloys to improve their resistance to demagnetisation at temperature, which is essential for the use of magnets in certain applications. Because of their use in these high-tech products, both historical and forecast data show a strong upward trend (Figure 14).

Going forward, the NdPr demand curve is seen to be steepening for these selected products, showing positive outlook for these metals. High demand for NdPr permanent magnets has changed the primary focus of some rare earth producers into specializing into producing products for magnetic materials, rather than the production of La and Ce compounds used in the petroleum or automotive catalyst industries. The use of NdFeB magnets in high performance electric motors for electric vehicles also presents a significant growth and value potential for companies involved in the rare earth industry.

FIGURE 14: Global Demand for NdPr Oxide.



Source: Lynas, 2019

3.4 Market Risk Resilience

Whilst the world is witnessing astronomical growth in REE supply and demand, it comes with its own risks. We have already explored the Chinese risk which is currently redefining market dynamics as the world seeks to de-risk the supply and obtain alternative sources of supply. In so doing the world is trying to create a market with reduced exposure to the risk of price volatilities resulting from China's policies on REE trade.

Another major risk is the COVID-19 global pandemic. The effects of the pandemic are obvious and transcend economic sectors, including the REE market. Among the known global effects are: disruptions to transport systems for the movement of resources (people, raw material, and goods); social distancing resulting in reduced productivity; illness resulting in shortage of labor; and operational shut down to limit the spread of the virus. The full extent of the pandemic effect on the financial and market dynamics as the pandemic is still ongoing, but supplies have been disrupted globally in the first quarter of 2020 and most mines and exploration ventures suspended operations. This is also reflected in the semi processed and the final product manufacture. With measures being taken to curtail the pandemic, production continues in China but is likely to make the market volatile and uncertain in the foreseeable future due to logistical and feedstock constraints (Argus Media)[1].

Many other risks are considered in later chapters, but the lessons learnt are clear – there is a need to create an environment that is more risk resilient. This is particularly important for Africa which is almost entirely dependent on foreign support for the functioning of its economy. The continent witnessed disruptions to supply chains, operations, and skills availability because of COVID-19, mainly because these resources are sourced from other continents. Development of metal value chains must be holistic and attempt to account for and mitigate the risk factors. For example, developing local skills and a 'home grown' supply chain with most of the raw material requirements for mining operations sourced locally can significantly mitigate the effects of COVID-19 that were witnessed in the past six months and any future pandemics. This calls for well-integrated strategies supporting the development of operations at country and regional levels to address existing constraints in the mineral value chain, especially the need to localise supply chains on the African continent.

3.5 Summary

Demand for high-tech products coupled with rapid global industrialization and population growth has placed increased pressure on the availability of raw materials including REE. Looking at the direction these technological developments are taking, it is reasonable to conclude that REEs will remain a sought-after commodity in the foreseeable future. Due to their use in strategically important high tech products like health and defense, many countries now consider REE an irreplaceable strategic commodity requiring clear guidance and policies on procurement to ensure supply availability. Whilst demand continues to increase, so does the risk of letting China maintain an effective monopoly of the industry.

In a bid to avoid risks resulting from China's trade policies, major REE consumers like the USA, the EU, Canada, Australia, Japan and Korea are exploring options to develop alternative REE supply chains. Africa is one of the continental regions

[1] *https://www.argusmedia.com/-/media/Files/white-papers/argus-white-paper-mixed-prospects-for-chinas-rare-earths-market-amid-covid-19.ashx*

targeted by these countries for alternative sources of REE commodities, a situation African member states should take advantage of to develop their own value chains.

Magnets and energy storage batteries are expected to be the key drivers for REE demand as countries seek to create a low carbon future by replacing fossil fuels with clean energy technologies like wind farms and electric vehicles. Demand is expected to vary among the 15 + 2 REEs, with the most sought after element driving the value chain. Critical REEs are expected to drive the industry forward with NdPr as the key component for the high-tech industry. Another driver for the REE demand is their use in advanced defence technologies used by the USA and other military superpowers.

Demand for REE is expected to remain buoyant in the long term as countries continue to implement policies that ensure a low carbon environment, and which will justify development of the value chain in Africa. The development however must address risks associated with the value chain, in particular, Africa must start looking into ways of developing a self-sustained supply chain and resource availability (skills, raw material and other enablers) to create a risk resilient economic environment.

04

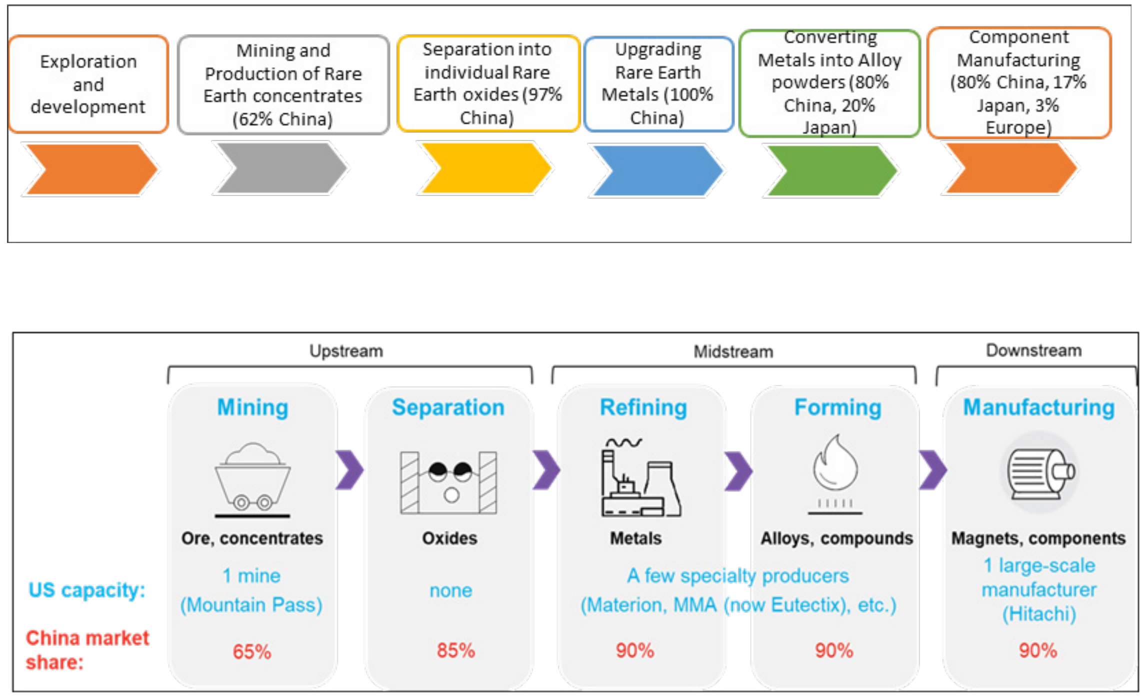
Overview of the Rare Earth Elements Value Chain

Like any other mineral, the REE value chain starts with an exploration process for the metal bearing mineral followed by mining, if the resource proves to be economic. The Run-of- Mine (ROM) ore goes through a series of processes until the desired product is attained (Figure 15). After mining and comminution, the ore goes through beneficiation processes, mainly gravity, floatation and magnetic separation to recover REE minerals in the form of a concentrate. This is followed by metallurgical processes of concentrate roasting and/or cracking, a process whereby the structure of the REE mineral is modified to dissolve REE in a weak acid solution to obtain the REE oxide (REO). This can be accomplished through various techniques such as alkaline cracking and acid baking. The cracked concentrate is then leached to dissolve REE in a solution and subsequently recover the metals via neutralization, precipitation or solvent extraction methods in the form of REE salt solution or powder and/or oxides.

The value addition processes can therefore be divided into 3 broad subcategories:

- the upstream end of the value chain comprising of exploration, mining and beneficiation with the main product being the REE concentrate;
- the midstream section comprising of hydro and/or pyro-metallurgical processes and produce mixed REE salts and separation and metal reduction at the downstream end of the value chain for the final production of REOs, individual element/metal, mischmetal or alloys depending on the target market; and
- the production of consumer products utilizing products in stage three. Consumer products by application include electronic, optical, magnetic, batteries, phosphors and catalytic applications.

FIGURE 15: REE Value Chain



Source: BloombergNEF, 2020

Note: U.S. capacity is defined as located in the U.S., not necessarily owned by U.S. companies.

FIGURE16: World Cobalt Production and Reserves in 2019

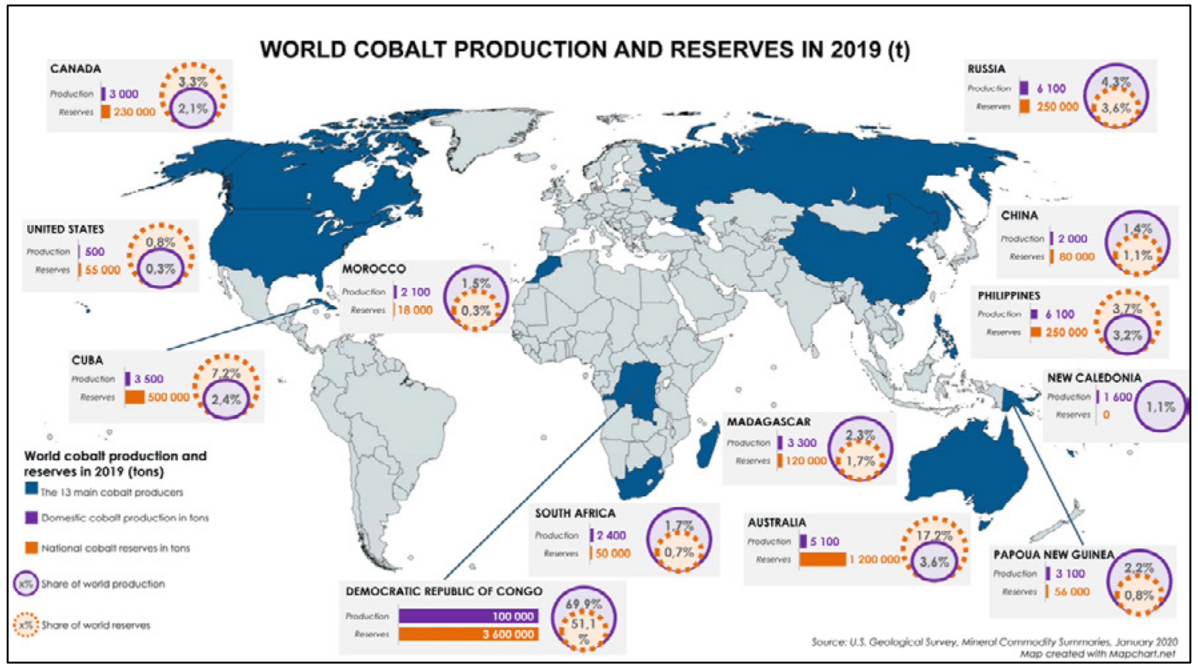


Figure 15 shows the REE value addition stages and the major players in the industry. China remains a major player to date, but its market share is gradually decreasing as other countries seek alternative markets to reduce the Chinese monopoly fears. China remains a major player in the whole value chain (Figure 15) followed by the USA as a major consumer, with about 91% of its REE coming from China as of 2010 (Figure 16). This percentage decreased to an average of 80% from 2014 to 2019. It is this dependence linkage the USA and other western countries would like to break by developing alternative sources like Africa.

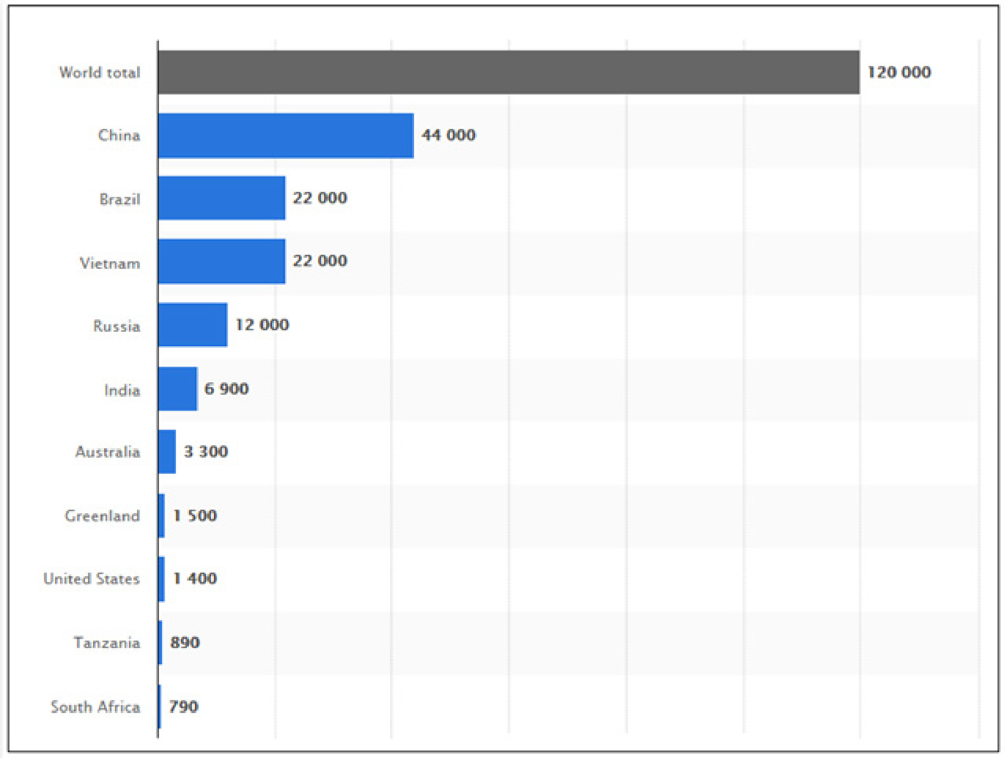
4.1 Mineral Resource Development

Exploration is the starting point for developing the REE value chain as it is the basis for discovering the mineral resource. The key stages of exploration are identical to those for most other metal exploration: to review existing information, remote sensing, reconnaissance, geophysical and geochemical analysis followed by resource evaluation, and finally development of the resource for production.

The dominance of China in the REE supply chain hindered exploration and development in other parts of the world. It was not until after 2010 that the world started to see investment in the rare earth industry when China reduced its export quota, which resulted in supply shortages and subsequent price spikes. Even then, several companies that had mushroomed around the globe in response to the price spike were forced to shut down operations around 2014/15 due to price uncertainty when China flooded the market at prices lower than the average cost of production in an REE operation. The intervention by the WTO in year 2014 banning China from its export quota system eased the scare and thus the industry started seeing investment and exploration and development picking up again. The sector remains a niche for the few that have managed to break in, particularly survivors of the 2014/2015 downturn.

Current and historical exploration work has identified several deposits and interesting prospective areas around the globe, including Africa. According to data from the USGS, the current world REE reserve stands at 120 million tonnes, with China representing 44 Million tonnes, equivalent to 37% of the world's total reserve (Figure 17). It is note-worthy that in 2018, China had almost 50% of the world's REE reserves (55Mt of 115Mt). The rapid drop in proportion of reserve is indicative of the supply and demand scenario in China whereby demand is outstripping supply. This is especially important as it represents a key opportunity area for new players in the industry like Africa to cover the gap. This shows, before reviewing the major REE reserves in other regions, that a market opportunity exists for new entrants like Africa. Reserves in Africa, and outside China, are known to have increased fivefold between 2010 and 2015.

Figure 17: Rare earth reserves worldwide as of 2019, by country (in 1,000 metric tons REO).



Source: USGS

The fact that South Africa and Tanzania are on the list of top ten countries by mineral reserves (Table 3) is a signal that Africa is positioned as a step on the ladder of the value chain. Several other projects are also known to exist elsewhere in Africa.

Based on the distribution of projects on the continent (Figure 8), it can be concluded that most of the REE development projects are concentrated in southern and eastern Africa where conducive geological conditions for deposition of the metals to economic levels have been known to exist for a long time. There are the magmatic alkaline/carbonatite deposits of the East African region associated with the East African rifting orogenic cycle, the vein type deposits of South Africa, and placer deposits. Strategically, Africa is likely to see more activity in these two regions in the immediate term but analogies in terms of geology and prospectivity can be drawn for generating targets in other parts of Africa for a full Africa-wide REE development of the value chain. Already there are carbonatite deposits in Mali and Mauritania and placer deposits in some parts of West Africa and Madagascar (Figure 8). In addition, several magmatic phosphate deposits in Africa have REE as by-products which could be put into full scale development with the support of a proper market development strategy in place.

A major upside for Africa's REE resources is the quality of the deposits, which is generally high because of secondary/supergene enrichment in the magmatic deposits and high HREE in the vein deposits. This has effectively attracted stock market-financed exploration by junior companies as the deposits demonstrate quality REE resource availability outside China. However, the challenge to transform some of these resources from exploration to production remain a major bottleneck due to price fluctuations. These are tied to the up scaling of beneficiation technologies, particularly for unconventional REE ore minerals, and to raising investment for project implementation. In this context, it is expected that the successful delineation of these REE resources will provide abundant options for expansion and investment in the industry, which are most likely to be harnessed by the dominant REE market player, China. Concerns about China's dominant role are therefore likely to persist, and if the major players can create a trade environment controlled by market forces it may be beneficial for the health of the industry. The industry saw Molycorp Inc of the USA succumbing to the fall in REE prices in 2015, although Lynas Corporation of Australia has thrived to this date with steady improvement in performance and profitability outside the Chinese market.

In Africa, several companies have defined mineral resources in their concessions, with two of them, Rainbow Rare Earth already producing REE concentrate in Burundi and Steenkampskraal Holdings restarting production at its Steenkampskraal mine in the Cape province of South Africa, which was mothballed for years. The two companies have developed their operations up to the beneficiation stage to recover a concentrate and REE in solution, respectively. These are positive developments for Africa as it seeks to develop a foothold in the industry. Table 5 shows some of the companies and their projects in Africa.

It is encouraging to see companies from major stock markets showing strong presence in Africa (Table 5), but also a major concern that no local African company is active in the sector. Africa's vision of achieving industrialization can only be reached by including local content in driving the business forward. A strategy must be put in place to promote local businesses in the economy and that should include the REE value chain. The strategy for developing successful 'home grown' value chains rests with the countries and regional groupings of the continent, dependent on the laws and policies they put in place to affect that success.

TABLE 5: Summary of selected REE projects in Africa.

Company	Stock Market	Projects	Country	Activity	Mineralization	Resource-X1,000 (%TREO)
Rainbow Rare Earth Plc	ASX	Gakara	Burundi	Mining, Exploration	Monazite, Bastinaesite	140 (54)
	ASX		Zimbabwe	Exploration		
SKK Holdings Ltd	Private (South Africa Market)	SKK Mine	South Africa	Reopening old Mine	Monazite	87 (14.4)
Frontier Rare Earth Ltd	Private	Zandkopsdrift	South Africa	Mine Development	Apatite, Monazite	950 (2.18)
Lynas Ltd	ASX	Kangankunde	Malawi	Exploration	Synchysite, Apatite	107
Mkango Resources	TSX/AIM	Songwe Hill (Several)	Malawi	Exploration	Monazite, Bastnaesite	370 (1.3)
Rift Valley Resources Ltd	ASX	Longonjo	Angola	Exploration	Monazite, Bastnaesite	Expected 500 (1)
Premier African Minerals	LSE	Several in North Western Zimbabwe	Zimbabwe	Exploration	Xenotite, Other minerals	(1.74) Early Trenching
Tantalum Holding Ltd	Mauritius	Madagascar	Madagascar	Exploration	Clay	220 (1.52)
Pacific Wild Cat Resources	TSX	Mrima Hill	Kenya	Exploration	Monazite	100 (3.1)

Sources: Company websites, Mining Journals, Mining-technology.com, 2019).

4.2 Mining and Project Development

Once exploration is completed and a mineral resource is discovered, the obvious transition is the progression to mining. Companies mostly progress to the mine development stage through fund-raising in the form of debt and equity. An information memorandum outlining the results of definitive feasibility study (DFS) is produced post the discovery of the REE resource and companies invest privately or through being publicly listed on any of the major stock exchanges, leveraging themselves on the appetite of investors in commodities as demand and REE metal prices remain buoyant on the market. Some companies already operating in Africa have been able to attract investment on the international markets like LSE, ASX, TSX-V (Table 5). This is an indication of the confidence investors have in Africa developing the REE value chain. In addition to debt and equity, several other funding options are coming on board driven by demand and strategic alignment to future long-term plans. Potential funders/offtakers include:

- auto manufacturers, who have announced plans to invest $300 billion in Electric Vehicles (EV) production and will need secure supply of strategic REE;
- funds driven by environmental, social and governance (ESG) concerns – delivering a low carbon future;
- governments – the US, Japan, Korea, and the EU are already taking steps to secure strategic national supply (e.g., Japan's financing of Lynas with an agreement to supply the Japanese market with its REE industry requirements).

To reaffirm how critical and strategic REE are to the developed world, Lynas signed a 10-year extension for the Japan Australian Rare Earths (JARE) loan facility, reaffirming Japan as a priority for the company's rare earths supply. The new agreement reduces principal repayments to nominal levels up to 2025, allowing Lynas to accumulate substantial cash flow from its operations (Australian Mining Journal[1]).

In addition to Lynas locking down an attractive funding structure, it gets to benefit from access to a ready market for its REE products, thus having a competitive edge over its peers. The Lynas – Japan deal is so attractive for Lynas such that it is not considering China as a potential market. With such investment options available, it is time for Africa to take full advantage of the market to develop its REE resources. The mineral resource is available in Africa and compares well with other projects globally, with superior grades and a higher HREE/LREE ratio, implying higher value on a one on one tonnage comparison.

Most REE mining operations in the world are open pit, mainly due to the nature of occurrence of the mineralization. However, underground mining may not be escaped, especially with steeply dipping vein deposits that cannot be exploited by open pit mining due to the high stripping ratios leading to excessive capex on waste stripping and mining. In addition to operations being developed specifically for REE mining, there are already several mining operations in Africa processing or with potential to process REE as by-products of their main commodity. There is the Rio Tinto owned Richards Bay Mineral Sands in South Africa, mining heavy minerals sands (zircon and rutile), and Monazite for REE as by products; Rio Tinto's Palabora Mine in South Africa is known to have monazite deposits at depth among the other multi-metals and vermiculite hosted by this carbonatite deposit; Compagnie des phosphates de Gafsa (CPG) of Tunisia has significant carbonatite phosphate resources, the exploitation of which has generated significant economic activity in the south of the country for over 100 years, and it's now exploring the possibility of exploiting the

[1]*https://www.australianmining.com.au/news/lynas-consolidates-japan-as-priority-customer-through-loan-extension/*

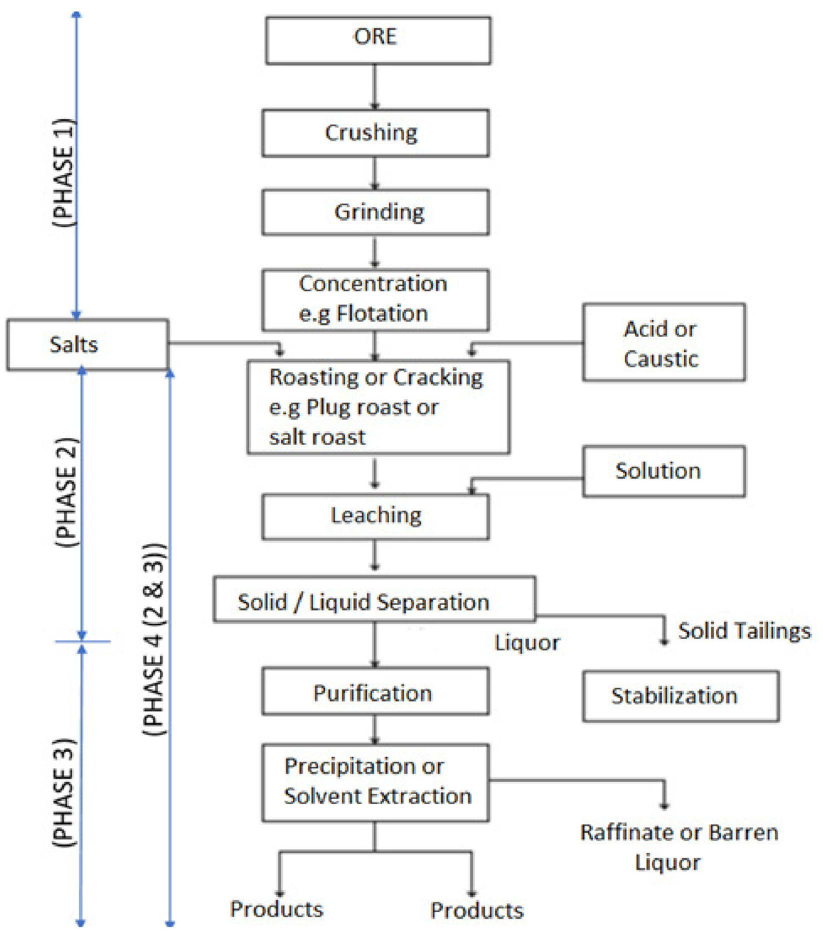
associated REE as a by- product. Other known multi-commodity carbonatites associated with the rifting orogenic cycle are either under development or exploration with REE as part of the main products of the operations. Uganda has a few companies developing the REE-bearing phosphate-magnetite alkaline carbonatites associated with the eastern limb of the East African rifting system.

From the few selected projects (Table 5), one project is already in production, two are under development and the remainder are still at exploration stage. An analysis of those projects in production or at the verge of production is showing positive results. Further details of four selected companies are provided as case studies in Chapter 5.

4.3 Value Addition to REE

REE ore is rarely sold on its own as a commodity, except in illegal operations which take place in some parts of the world, particularly in China. After mining, ore undergoes comminution to liberate the REE minerals, followed by beneficiation processes to separate the REE mineral from gangue minerals and impurities. REE ore is often beneficiated within striking distance of 1 to 2 km from the mine site, but can be located further away depending on circumstances like the availability of space for the process plant. In most cases, beneficiation of rare earth elements adopts the technological process of flotation, often accompanied by various combinations of gravity and magnetic separation, resulting in a high-grade concentrate that normally contain about 80% of the valuable minerals (such as monazite, bastnaesite and xenotime).

FIGURE 18: REE Value Addition Flow Process



Source: SGS[5]

At this stage, the concentrate can be commercialized as the final product for the market, making mining and beneficiation stages a commercial business unit in some operations. Figure 18 shows REE value addition phases as potential business commercialization units mapped against the value chain flow process from Phase 1 to Phase 3. Commercializing mining and beneficiation as an entity would imply selling the product as a concentrate to another company operating at Phase 2 for further metallurgical processing, with the company at Phase 1 realising revenue from the sale of the concentrate. Rainbow Rare Earth adopted this business model for its Gakara mine in Burundi, selling concentrate to its off-taker in Germany.

[5] *https://www.sgs.com/-/media/global/documents/flyers-and-leaflets/sgs-min-wa368-rare-earth-ore-processing-en-11.pdf*

For start-up companies in Africa, establishing a mining business unit with concentrate as the final product can be a good entry point. It could be simpler and easier to implement at a lower Capex than establishing an integrated system. Even though there is little value addition at this stage, it is important that companies understand the market and the technological dynamics of the REE before venturing into the more sophisticated downstream value addition processes like cracking, separation, and metal reduction. Also, commercializing at beneficiation level (concentrate production) has the benefit of shortening the payback period for start-up operations, making the investment attractive for potential investors. The only downside is the heavy discount on the sale of concentrate. Rainbow sells concentrate to TK of Germany at a discount of 70% of its basket price.

To establish a fully integrated project incorporating all the phases of value addition, the project evaluation must be thorough to justify investment especially as concentrate, which is the driver of the asset value, can vary significantly depending on the REE assemblages. A predominance of LREE may prove uneconomic due to depressed prices fetched by the LREE constituent elements on the market, whereas a concentrate dominated by HREE might meet all the requirements for economic viability due to their higher prices on the market.

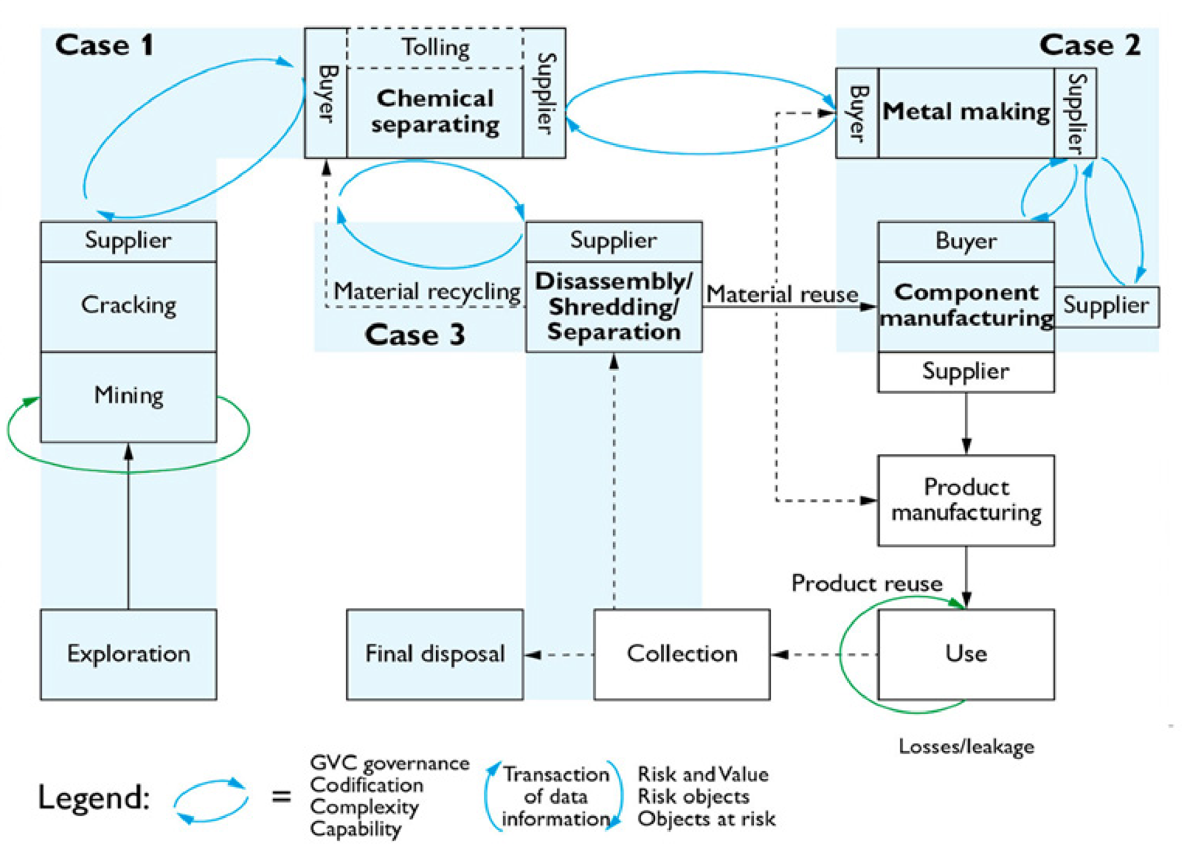
Metallurgical processing can be designed as a standalone business unit (Phase 2 of Figure 18) that employs complex pyro- and/or hydro-metallurgical processes to further concentrate the REE minerals to oxide form (REO) for further downstream chemical separation processing. This means the company operating at Phase 2 buys concentrate as its raw material feed from miners, as TK does from Rainbow. Once an REE-containing concentrate has been produced by physical ore beneficiation, the next steps are dissolution, separation, and purification of the REE.

Both pyro and hydro-metallurgical processes can be accommodated in Phase 2 illustrated in the flow diagrams (Figures 18,19) with commercial products being total solids or REE cations in solution respectively, depending on the method used. Either the TREO or REE solution/salt, or both, feeds into Phase 3 of the flow process as raw materials to produce the final product, which could be individual REE oxide (REO), metal or alloy (mischmetal). Alternatively, Phases 2 and 3 process units can be combined as one business unit (Phase 4). In a fully integrated operation incorporating all the three phases, where the REE deposit can support such viability, the saleable product after the processes of mining, beneficiation metallurgical processing and separation are separated into REOs, alloys/mischmetals or pure REE metal (99.999% purity). However, for operational efficiency, it is prudent to divide the operation into standalone units as shown in the flow chart, even if no intermediate commercial product is produced.

For maximum benefit, governments should promote investments that support the establishment of the whole value chain where big mining operations can develop their own end-to-end integrated process plants, and junior mining players can pool resources to supply centralized in-country or regional end-to-end integrated process plants. With such facilities in place, consumer industries like manufacturers of magnets, batteries and LED products would gradually start to grow once the quality and sustainability of REE supply for their operations is proven.

In the African situation, there are three commercialization options currently being implemented by the three front runner companies. Rainbow Resources produces concentrate as its final product equivalent to Phase I of the REE value chain, SKKH is poised to have rare earth nitrate solution as its final product (Phases I and 2 in Figure 18), and Frontier is developing an integrated REE process covering the whole value chain (Phases I, 2 and 3) to produce separate REOs as its saleable/commercial product. The choice of which stage

FIGURE 19: Phases of REE Mineral value chain.



to commercialize is dependent on several factors including the availability of capital, complexity of the mineralization, off taker preferences, and market dynamics.

The final stage in value addition is the supply of REE products to the consumer industry which needs the REO, alloys or pure metal for components like magnets and batteries, which are supplied to customers like makers of wind farms for magnets or manufacturers of EV. Figure 19 shows the value addition processes presented as cases where Case I is the upstream stage from exploration and mining to the production of separated products (REO and mitchmetals) which feeds into Case 2 involving metal making, and component manufacturing and supply to the product manufacturer and end users. Case 3 involves the collection of used REE products which feeds into the intermediate zone between Case I and case 2 for recycling and reprocessing to separate the used components for feeding into Case 2.

Case 3 in figure 19 is however still in its infancy as very few REE .products are currently being recycled which could be due to a lack of sufficiently economic quantities to warrant active recycling. With time, the world will witness increased use of REE due to ramped up demand as countries continue to ratify policies on curbing greenhouse gas emissions, and this will in turn require green energy options that imply the use of large quantities of REE that will make recycling more viable. Commodity prices are also expected to rise in future as demand increases, which will also support economic recycling of REE products.

4.4 Summary

The REE supply chain remains a niche dominated by China. However, the projected demand for a low carbon future globally, and China's loosening grip on the market are opening doors for a wider participation from other players. Many of the REE consumer states outside China are keen to see a better level of competition in the supply chain as a way of mitigating China's risk and to ensure stable supplies of raw material. This is an opportunity Africa should take advantage of to establish its own REE value chains.

The value chain can be segmented into three phases, with exploration, mining and beneficiation constituting the upstream phase of the value chain (Phase I), metallurgical processing, separation and reduction forming the intermediate stage (Phase 2), and the final stage of manufacturing consumer goods (Phase 3) constituting the downstream stage of the value chain.

Africa is already developing the value chain in various parts of the continent, with several companies carrying out exploration in several regions, particularly southern and eastern Africa. Integrated results of the exploration show potential for a discovery of 4 million tonnes of contained REO.

Rainbow Rare Earth mining company is already mining and processing ore into a concentrate it sells to TK of Germany under their 10,000t/y TREO offtake agreement, while two projects in South Africa, Steenkampskraal and Zandkopsdrift, are at development stage, taking their projects to Phase 2 and Phase 3 of the value chain, respectively.

Considering the various commercialization stages available in the value chain, Africa should strive to attain maximum benefit from its investment in the industry. Africa should promote, as much as possible, the establishment of the full value chain from exploration to production of consumer products. In countries with deposits that are too small to establish an integrated process system (Phase 1 to 3), countries should be encouraged to establish regional process plants that can utilize the various small mining operations in the regions. African States can actively pursue value addition through to Phase 2 (production of final REE product for sale to consumer goods manufacturers) either as standalone process systems integrated with the mining operation or as a separate entity receiving concentrate from various small mining operations in country or as a collective regional development.

Development finance institutions can work closely with African governments to understand the needs of these REE development companies and provide them with support to ensure maximum benefit from the REE business.

05

Africa's Position on the Value Chain and Regional Approaches

It has been demonstrated in section 2 that Africa has significant REE resources, and several projects are in development, mainly exploration and feasibility. The only producing mine is Rainbow's Gakara Mine in Burundi, even though it is yet to officially announce its mineral reserve. This section investigates some selected projects and their potential significance to their host countries and to the continent. The chapter also investigates the possibilities of developing regional or Africa-wide synergies to enhance capability, efficiency and competitiveness.

5.1 Case Studies

Four REE mineral resource development projects were selected for detailed more study mainly because of the significance of the deposits as well as the availability of robust data about them. The four are Makuutu Project in Uganda, Gakara project in Burundi and Steenkampskraal and Zandkopsdrift projects in South Africa.

5.1.1 Case Study 1: Makuuku Project, Uganda

The Project

Makuutu project, which is owned by Ionic Rare Earth company (Ionic), an Australian company registered on the ASX market, comprises three licences covering approximately 132 km2 located some 40 km east of the regional centre of Jinja and 120 km east of the capital city of Kampala in eastern Uganda. The area has excellent infrastructure with tarred roads, nearby rail, power and water, cell-phone coverage, as well as being readily accessible throughout the year, irrespective of weather conditions.

The project's geology is like the southern China ionic clay-type deposits, which are the cheapest and most readily accessible source of heavy Rare Earth Oxides (HREO) that are extracted through rudimentary mining and processing methods. Mukuutu is significant in size and is understood to be potentially one of the largest ionic clay deposits outside China, with grades consistent with these types of deposits.

Project Description

Maiden mineral resource estimates resulted in an inferred resource of 47.3 Mt at 910 ppm TREO, at a cut-off grade of 500 ppm TREO-Ce2O3, with contained TREO of close to 50,000t. By subtracting the Ce component from the grade tonnage figures, Ionic does not foresee cerium being marketed, which is logical considering the low price cerium fetches on the market. Based on the information obtained to date, Ionic's target resource is in the range of 270 – 530 million tonnes grading 0.04 – 0.1 % TREO, which is expected to be mined using open pit mining methods.

Processing

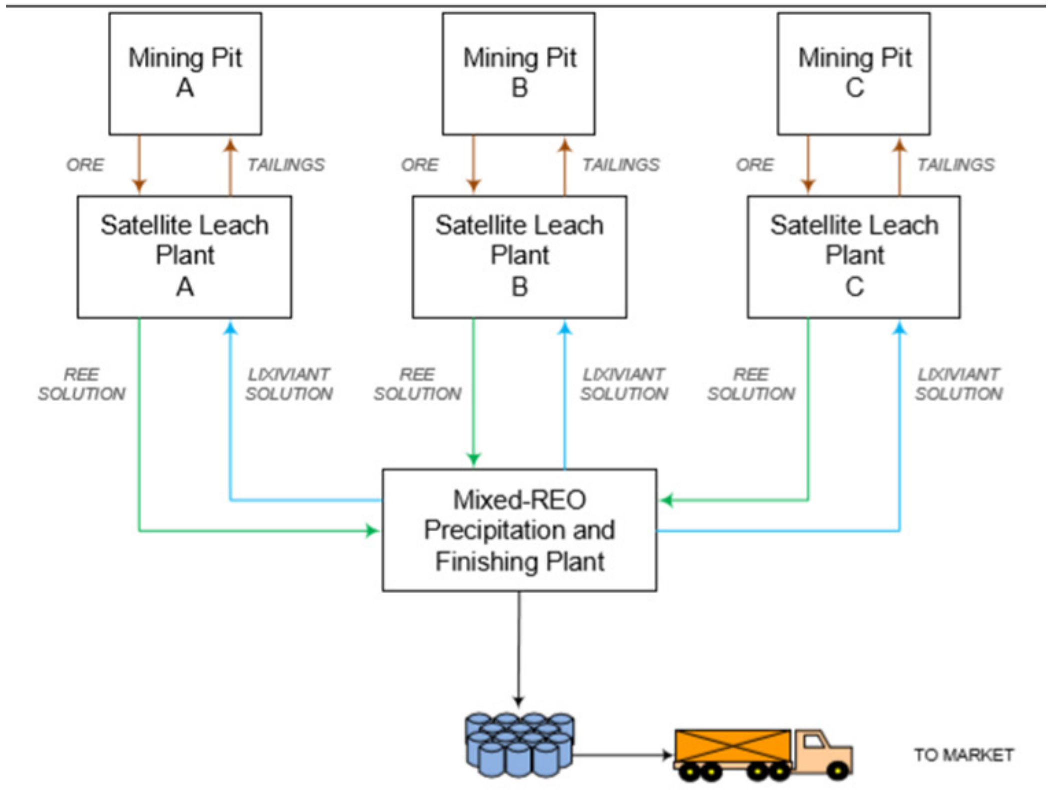
Ionic's clay rare earth projects vary markedly from hard rock rare earth projects. Typically, rare earths can be recovered from ionic clay mineralization using mild leaching conditions. Preliminary metallurgical results for the company are highly promising, with the majority being high recoveries from low reagent (salt and acid) use enabling a very low-CAPEX leaching operation to liberate the rare earth elements for precipitation and sale. The company is currently exploring a project configuration that consists of several low-CAPEX satellite leaching and desorption plants from which concentrated rare earth streams will be transferred to a central plant for finishing and packaging as shown in the envisaged configuration presented in Figure 20.

Development of ionic clay deposits like the Makuutu is easy, simple and cost effective compared with hard rock operations. Table 6 compares both processes.

Business Model

Ionic plans to finish the value addition process with the production of mixed REE. Metallurgical tests are underway to evaluate this option. This implies Ionic will sell mixed REO to another company that will process the mixed REO before selling at a higher price to consumer goods manufacturers.

FIGURE 20: Conceptual arrangement of the envisaged Makuutu Rare Earths Project.



Source: Source: Ionic Rare Earth

Business Support

With the support of the government, Ionic can further develop its process industry to Phase 3. In the Uganda scenario, there are other industry developments that would support the development of the REE value chain to Phase 4. Kiira Motors is on the verge of completing the development of its HEV plant which will soon require batteries for its electric cars. The cobalt and niobium needed to make these lithium batteries is available from the Kilembe copper-cobalt deposit in Western Uganda, and from deposits in northwest Uganda close to the border with DRC. Besides Kiira motors, Uganda has petroleum which is ready for production and requires cracking given that the type of petroleum is the heavy type. The Ugandan government, with the help of institutions like AfDB, can co-finance phase four part of the value chain, thus creating a market for Ionic's REE products. This will ultimately create an end-to-end value chain encompassing vertical and lateral integration, with significant benefits to the country in the form of revenues, employment, and support industry development.

TABLE 6: Comparison of value chain development between ionic clays and hard rock projects

MINING/ PROCESSING STAGES	CLAY – HOSTED REE	HARD ROCK - HOSTED REE
Mineralization	• Soft material, negligible (if any) blasting	• Hard rock
Mining	Low operating costs: • Surface mining (0 – 15m) • Minimal stripping of waste material • Progressive rehabilitation of mined areas	High operating cost: • Blasting required • Could have high strip ratios
Processing – Mining site	• No crushing or milling • Potential for static or in-situ leaching • Ambient temperature • Simple process plant	• Comminution followed by beneficiation that often requires expensive flotation reagents
Mine product	• Mixed high grade rare earth precipitate (50 – 95 % depending on precipitant) for feedstock into rare earth separation plant	• Mixed REE mineral concentrate (typically 20 – 40% TREO)
Processing – Refinery (Typically, not on mining site)	• Simple acid solubilization followed by conventional REE separation. • Complex recycling of reagents and water	• High temperature mineral "cracking" using strong reagents • Complex plant (to withstand strong reagents and high temperatures) • High reagent consumption per tonne of REO
Processing – Environmental	• Non – radioactive tailings • Solution treatment and reagent recovery requirements (somewhat off-set by advantageous supporting infrastructure)	• Tailings often radioactive (Complex and costly disposal)

Source: Ionic Rare Earth

5.1.2 Case Study 2: Gakara Project, Burundi

The Project

Gakara project, which is owned by Rainbow Rare Earth company (RRE or Rainbow) which is listed on the London Stock Exchange, lies 20Km south of Bujumbura near Lake Tanganyika. The project is in an area with excellent infrastructure with tarred roads making it readily accessible throughout the year, irrespective of weather conditions.

The deposit is hosted in a carbonatite complex with bastnaesite and monazite as the main mineralization in numerous veins within the deposit. The deposit, arguably the richest in the world with retained grades ranging from 47 to 67% TREO, is a highly weathered deposit where the mineralized veins of almost pure bastnaesite/monazite, resistant to weathering, are exposed as ridges within the weathered matrix.

Project Description

The project started producing concentrate on a trial basis from 2017, followed by commercial production and plant commissioning in 2018, even though there is no mention of the size of the mineral resource/reserve in the public domain. Rainbow already has a ten-year offtake agreement to supply 10,000t/y of concentrate at 56±2% REO to Thyssenkrupp Materials Trading of Germany since 2017. By signing an offtake agreement, it shows the company is confident about the existence of at least 120,000t of CREO to cover the period of the offtake agreement. A report on global rare earth resources by Baolu Zhou et al[2] estimated that Gakara has 256,500t of ore at 54.3% CREO, which is equivalent to 139,280 tonnes of TREO, a confirmation of the availability of the empirically calculated resource of 120,000t CREO derived from the projected pit optimization (10,000t annual concentrate delivery to TK for a period of ten years).

The retained grades from exploration are super high, ranging from 47-67% TREO as the mineralization is in the form of seams of almost pure bastnaesite/ monazite hosted in highly weathered lateritic material; and the basket is weighted towards magnet REE, with NdPr representing more than 80% of value (but 19.5% of mass). The fact that the ore veins in the carbonatite complex occur in a highly weathered lateritic matrix has made it possible to practise hand cobbing of the ore/mineral veinlets with high precision, thus minimising ore contamination from the country laterite material. The high grade scenario could change with depth as the degree of weathering diminishes into fresh carbonatite but for now, it makes the Gakara deposit the richest known REE deposit in the world. Considering that the mine is 'free dig' without the need to use explosives, it implies capex on establishing the mine would be exceptionally low, and the operational expenditure would be modest as neither heavy mining equipment nor skilled personnel are required to run the mine. Considering most of the carbonatite deposits in the region are similar, it would be reasonable to conclude that many of the other projects in the region have the potential to achieve similar profitability, or even higher revenues for the potentially bigger deposits like Mkango Resources' Songwe Hill deposit in Malawi, which may have over half a million tonnes of REO. Planned properly, REE deposits in Africa can be a game changer for the continent to transform its economic fortunes in a sustainable and environmentally friendly manner.

Mineral Processing

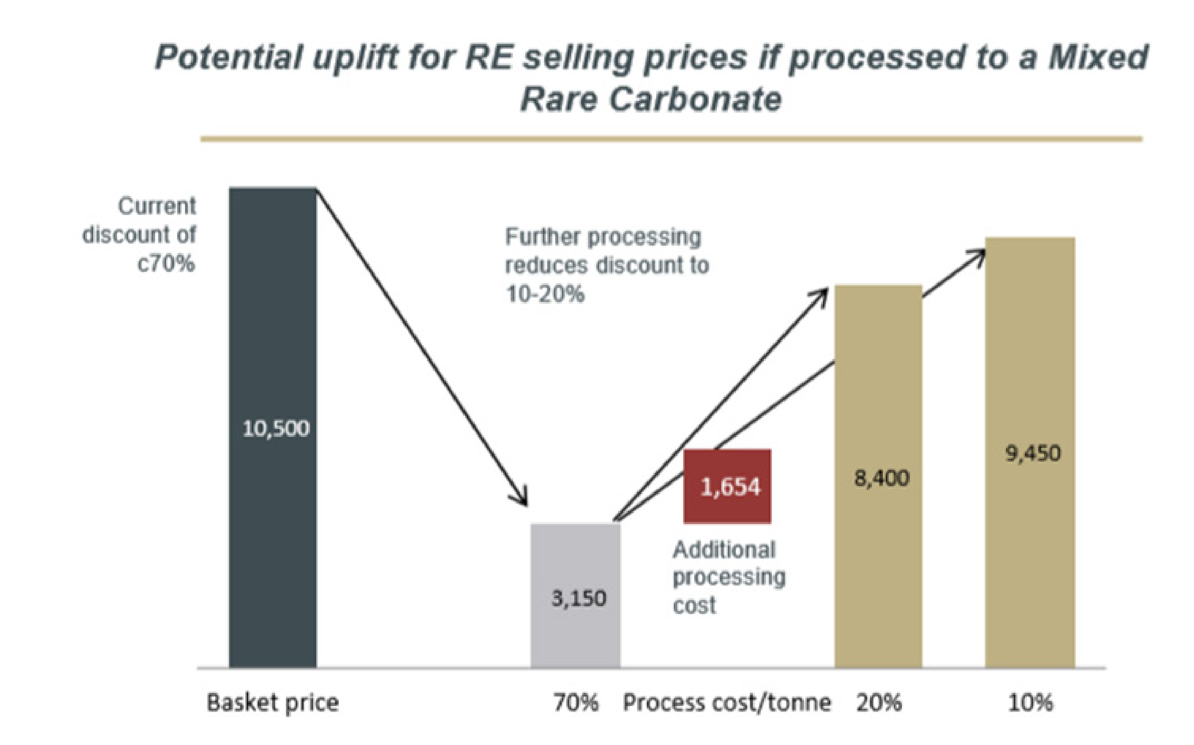
At Gakara Mine complex, Rainbow utilizes a process plant with the capacity of treating five tonnes per hour of RoM ore. The ore goes through the process

of comminution, followed by gravity separation using one jig and two shaking tables to separate gangue material from the denser REE minerals. Crushers, conveyor belts, a filter press, pumps and tanks complete the basic equipment of the plant. Though no further details on the processing of the ore is provided, it is possible to upgrade the ore to concentrate through washing and gravity separation alone at this stage due to the high weathering of the deposit at shallow levels. With TREO grades of 56%, the hand-cobbed ore is almost a concentrate before any further beneficiation is done. As the mine deepens with production, it is possible that Rainbow will have to recapitalize and invest in additional plant technologies that can handle fresh or less weathered rock material.

Once the ore is concentrated and filtered to specific moisture content, it is bagged for shipment to the offtaker, Thyssenkrupp Materials Trading (TK) of Germany. For REE in concentrate form, the norm is for the miner and the client to agree on the terms of sale – normally a percentage of the basket price is agreed between the two and, in some contracts, the price excludes the operating cost incurred by the customer for further metallurgical processing and REO separation. Rainbow and TK's agreement means Rainbow sells the concentrate to TK at a 70% discount to the published REO prices. Rainbow is therefore forfeiting 70% of its potential revenue by ending the value addition at Phase 1. According to Rainbow's metallurgical tests carried out by SGS, further processing of concentrate can significantly reduce offtaker costs from 70% to around 20% as shown in figure 21. According to SGS scope study, this would however require investment of $20-25 million capex and $1,654/t opex for a 10,000tpa TREO production with the subsequent effect of increasing revenues from the current $17m to $48-55m per year.

[2] *https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjp_Jm-H4IjpAhXXSBUIHZnjBPEQFjAAegQIARAB&url=https%3A%2F%2Fwww.mdpi.com%2F2075-163X%2F7%2F11%2F203%2Fs1&usg=AOvVaw2BEUIV0migdrxO0uo6cVQB*

FIGURE 21: Benefit of value addition for REE processes.



Source: Rainbow , 2020

The Rainbow scenario of beneficiating to concentrate stage (Phase 1 in Figure 18) is a clear demonstration of the benefit of value addition. From a basket price of $10,500/t, Rainbow realises $3,150, or forfeits $7,350 towards the cost of processing and separation by TK, the German offtaker. By adding value to Phase 2 or 3 (Figure 14), Rainbow's earnings can be increased to $8,400 or $9,450 respectively, with only an in-house additional processing cost of around $1,654/t. If Rainbow can raise the required investment of $20-25 million to build the infrastructure for establishing Phases 3 and 4, the revenues are clear and the payback period predictable.

Rainbow's operation is the simplest it can be in any business commercialization: it operates a mine and a processes minerals with the REE concentrate as the final product for sale. It is possible that Rainbow is the only company beneficiating its ore to a concentrate as the final product outside of China. Other companies choose to integrate further down the value chain in order to add value to their product. It could be that Rainbow's strategy is to use its revenue streams to finance the next phases of the operation. It has already shown in its 2019 financial report that the loss it incurred was mainly due to financing costs. For start-up companies with little capital, it can be a good strategy to use revenue streams to finance project or business expansion rather than going back to shareholders for a rights issue. At a national level, it can be argued that the potential 70% loss of revenue is also a loss to the host country not only in terms of revenue but other economic areas like employment creation, support industry development, GDP, or foreign currency impacts.

Value addition brings significant benefit to the host nation through the development of a support and service industry to supply the integrated operation. Positive ripple effects include providing an employment boost, skills transfer and paying corporate and withholding tax. Governments and regional groups should therefore support any entity that thrives to develop the value chain and add value to its product. The support can include a range of measures in the form of incentives on capital goods imports, tax concessions during development to accommodate downstream development of the value chain or establishing regional or continent-wide free trade zones. With a sound feasibility study in place, development banks like the AfDB can work closely with governments to ensure the maximum benefit to the country or region.

Business Development

Rainbow was successfully listed on the London Stock Exchange with an oversubscribed placing to the tune of £8 million being raised - a huge success for a junior start-up company. The listing also attracted several institutional investors, an indication of the confidence investors have in the market for developing REE minerals in Africa. International stock markets are some of the opportunity avenues the continent can tap into for raising capital, but African states should be encouraged to build and develop their own homegrown investment platforms comprising of stock markets, investment banks, pension funds, insurance funds, and hedge funds. Following this success, Rainbow is now looking for additional funds for project expansion.

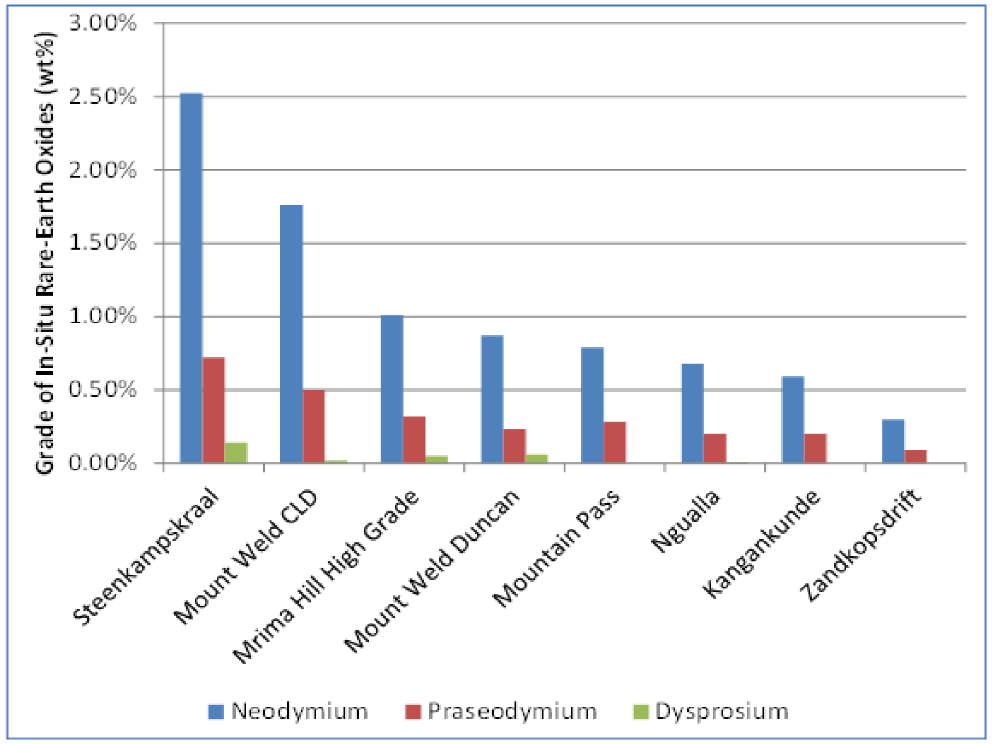
5.1.3 Case Study 3: Steencampskraal Mine (SKK), South Africa

The Project

Another important investment development is the resuscitation of Steenkampskraal (SKK) mine after it was mothballed in 1963. SKK is in the Western Cape Province of South Africa, approximately 330km North of Cape Town and 90km East of the Atlantic Ocean.

SKK is a single vein deposit with monazite as the main mineralization. The monazite is associated with the radioactive thorium, which means the mine requires special disposal measures for the radioactive material to ensure limited radiation exposure to the workforce. In terms of grades, SKK and Gakara are the two REE deposits with the highest grades in the world. Figure 22 shows the in-situ neodymium (Nd), praseodymium (Pr) and dysprosium (Dy) oxide grades for selected projects. Also noteworthy is the Mrima Hill of Kenya with relatively higher grades than most of the deposits in Figure 22.

FIGURE 22: Nd, Pr and DY in-situ grades for selected projects, 2020 (After SKKH)



Whereas Gakara is a carbonatite deposit, SKK is vein-type deposit intrusion into the formation of a mobile belt in a similar manner to its nearby Zandkopsdrift deposit.

Project Description

The company, Steenkampskraal Holdings (SKKH) has carried out a feasibility study and are currently raising equity finance on the South African market for the development of the mine. Of the many planned open pit operations on the continent, SKK mine is the only project planned for an underground mine due to the nature of the deposit – a narrow and almost vertically dipping vein. In any case, the mine was historically operated as an underground mine, and as the old infrastructure is still in place, it is financially advantageous and quicker for the company to pursue the same type of mining utilizing the existing haulages and access adits. The mine design is based on a conventional vertical retreat open stopping technique - tramming the ore to the bottom of the incline shaft and hoisting it to the surface using a vertical shaft. With a target production rate of 2,700 tons of contained REOs per year and an average mined grade, after allowing for dilution, estimated at 8.68%, the mine will produce about 31,000 tonnes of ore per year, and at this rate of production, the mine life will be about 25 years. According to SKKH, the high grade and the small tonnage means low mining costs.

Mineral Processing

SKKH's processing approach involves the use of gravity separation and flotation to produce a high-grade concentrate that contains about 80% monazite. A concentrate containing copper, gold and silver is also produced as a by-product during this phase. The monazite concentrate is chemically cleaned to remove residual apatite and sulphide contamination, after which it will be treated with caustic soda to render the rare earth elements soluble in a dilute acid solution. SKKH has chosen to remove cerium from the rare earth salt mix and the cerium-depleted mixed rare earth carbonate will then be sold to companies that separate the individual rare earth oxides. Cerium is to be refined on site for sale in South Africa, probably due to market availability in the country. In many deposits, cerium is more of a nuisance than a valuable commodity. It is the most abundant but at a price of $1.85/kg (Nov 2019), it is the least valuable of the group of metals. Transporting it with the other REE all the way to a distant foreign market, would be more costly than selling it locally or stockpiling it in anticipation of a future price rise.

Business Model

SKKH, by commercializing the REE salts, plans to add value to the commodity until Phase 2 (Figure 18). In comparison to Rainbow, SKKH is locking in 70% more of the value of the commodity by beneficiating it further to Phase 2.
SKKH is raising capital through private equity and debt funding on the South African market. It is important to note that South Africa has a relatively strong financial base for raising funds for investment. This is the direction African countries should follow – to be able to finance their own projects in addition to foreign direct investment. Home grown financial facilities have the advantage of strengthening the financial markets in the country and therefore stimulating economic growth.

5.1.4 Case Study 4: Zandkopsdrift Project – South Africa

The Project

Zandkopsdrift is located in Western Cape 450km North of Cape Town and is 300km from the deep seaport of Saldanha Bay. The project area is well connected by tarmac road and close to an international airport, and it lies in the same region as Steencampskraal.

Frontier Rare Earth is one company developing the Zandkopsdrift (ZKD) deposit in Northern Cape, South Africa, hosted in numerous veins of a carbonatite ring complex. Unfortunately, data for this development, with almost a million tonnes of REO, could not be obtained for a detailed analysis of the development and its status, but the results of its economics assessment from the pre-feasibility study were highly positive.

Project Description

Production at 20,000t/y REO is expected to run more than 40 years with a net present value of $3.65 billion at 11% discount rate. The capex was estimated at $910 million with a payback period of two years, with free cash after tax of $700 million per annum in subsequent years. At this level of investment, Zandkopsdrift could be the largest REE investment outside of China, and with a payback period of two years and profitability close to a billion dollars per annum, its figures are highly attractive. Frontier Rare Earth Ltd, which is now privately owned, having previously been listed on the Toronto Stock Exchange, partnered with Korea Resources Corporation ("KORES"), which is owned by the Korean government, to make an agreement similar to the Lynas and Japan loan agreement (Reuters[3]). By entering this partnership, Frontier Rare Earth has developed a huge market for its products, with KORES seeding an initial $23 million for 10% of capital and operating costs, which effectively gives KORES access to 10% interest in Zandkopsdrift, thus allowing it to purchase 10% of rare earth production at open market prices from Frontier Rare Earth Ltd. Kores has the option to form a consortium of Korean companies to participate in the joint venture including Samsung Group, Hyundai, GS Caltex and Daewoo Shipbuilding. This points towards a smart market creation that circumvents the vagaries of the Chinese market. The project, with a life of mine (LoM) in excess of 45 years, surely provides a model for Africa to develop a clear strategy to become a key influencer of the future of the REE market, including local content participation in the value chain.

Mineral Processing

Whereas SKKH is taking the commercialization route down the value chain to produce an REE salt mix, Zandkopsdrift is taking the process further to the downstream end of the value chain to produce separated REOs. Its processing route is however different to that of SKKH after milling. SKKH uses the flotation and salt production route whereas Frontier follows the leaching route and thickening stages with the production of manganese sulphate (MnSO4) as a by-product at the pre-leach stage.

Frontier entered into a fixed price BOOT (build, own, operate and transfer) contract with Outotec of Germany for an acid mixing, low temperature cracking, high temperature calcining, off-gas treatment, sulphur recovery

[3] *https://www.reuters.com/article/frontier-kores/update-1-frontier-signs-deal-with-kores-on-rare-earth-project-idUSL3E7N525D20111205*

and sulphuric acid plant design, a type of agreement for Outotec to design, procure, build, commission and operate the leaching process plant for a period of two to three years, depending on when it recoups the agreed price, before handing over the operation to Frontier. The process plant system comprises of monazite sulphuric acid cracking process principally through Outotec's fluidized bed reactors/roasters (as opposed to horizontal kilns commonly practised elsewhere). According to Frontier's pre-feasibility study, the tailor-made process has several advantages compared to other processes in the world:

- More precise temperature and residence time control for effective cracking;
- Produces dry, free-flowing feed instead of wet paste;
- Eliminates acid condensation, which prevents corrosion, as temperature is maintained above acid dew point;
- Allows 80% recovery of sulphur, unlike Lynas and Molycorp's which had no recovery;
- Allows approx. 99% stabilization of impurities, resulting in lower impurity removal costs;
- Reduces residence time from about 1 hour to 10 minutes or 80% reduction;
- Operational stability and significantly improved process control - no material build up or blockage, efficient heat transfer - approximately 50% heat recovery;
- Lower operating costs.

At this stage, Frontier recovers an REE hydroxide product for the separation process and the residual solution is channelled to the effluent treatment plant for final dumping at the tailings disposal facility. The REE hydroxide is transported 300km to Saldanha Bay where Frontier's proposed separation plant is to be built. This is where the final product of REOs is produced and dispatched for the market.

Like SKK, the ZKD monazite resource is associated with thorium which requires special treatment and disposal to avoid radiation harm to people who come into contact with it.

Business Model

It should be observed that some companies are taking value addition all the way to the final phase of producing separate REO. For the size of ZKD, it would be interesting to review a detailed analysis especially on the economic impact the project is likely to make to the country on employment and taxes. This is the business model that should be encouraged in the present circumstances where demand from the consumer market is not yet well established to warrant manufacturing of consumer goods for local/regional consumption.

5.2 Comparison with other REE projects in the world

This section endeavors to compare operational approaches and draw analogies to identify areas of opportunity for improvement within the value chain. REE exploration is taking place across the world suggesting not all players are prepared to permit China to dictate the economics of this strategic commodity. From a review of the distribution of the known deposits, Africa can be an active player in the REE value chain business if it promotes the development of those deposits and continues exploration for more discoveries. Table 7 provides a comparison of some known deposits (based on the factors stated) and the companies developing those deposits.

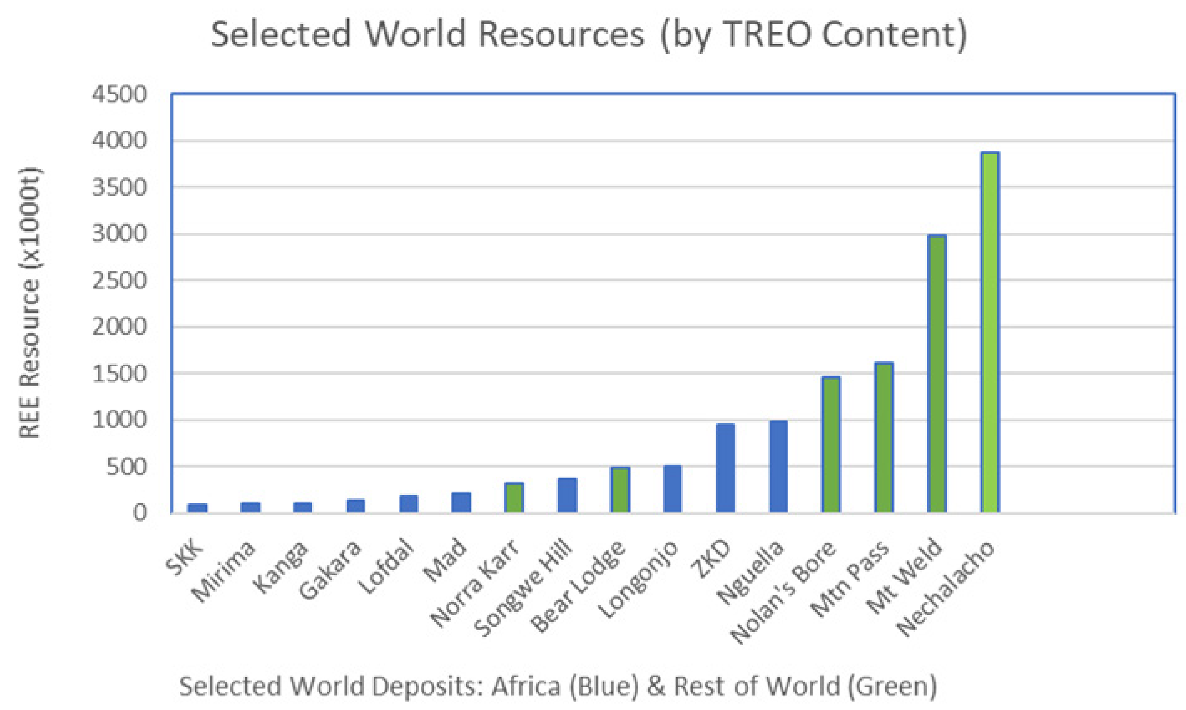
TABLE 7: Comparison of selected deposits, 2019

Deposit	Company	Location	TREO Resources X1000t	Grade (%TREO)	Basket Price ($/Kg)	Critical REO Content (%)	Tpa	Capex (X $1M)	Opex($/Kg)	Separated REOs	Stage in Progress	Primary REE mxl.
Nechalacho	Avalon	Canada	3870	1.3	36.42	33	10			No	PFS	Eud
Mt Weld	Lynas	Aus	2980	5.4	21.54	20	22			No	PFS	Kai
Mtn Pass	MP Materials	USA	1620	8.1	14.69	12	19			No	PFS	Anc + Bas
Nolan's Bore	Arafura	Aus	1456	2.6	22.73	23	20			Yes	DFS	Apa + Moz
Nguella	PR NG Minerals	Tanzania	980	4.9	18.87	17	10			Yes	DFS	Ferg
ZKD	Frontier	RSA	950	2.18	22.53	22	20	910	11.9		PFS	Bas
Longonjo	RVR	Angola	500	1			N/A	N/A	N/A	Yes	Prod	Bas
Bear Lodge	Rare Element	USA	498	3.05	22.95	21	7.5			Yes	Prod	Mon
Songwe Hill	Mkango	Malawi	370	1.3			N/A	N/A	N/A		Expl.	
Norra Karr	Tasman	Sweden	324	0.7	46.69	51	5				Expl.	
Mad	Tantallum	Madagascar	220	1.52			N/A	N/A	N/A		Expl.	
Lofdal	Namibia	Namibia	185	0.8	70.63	70	1.5				Expl.	Mon/Bas
Gakara	Rainbow	Burundi	140	54			10	10	1.53		Expl.	Mon/Bas
Kanga	Lynas_M	Malawi	107	4.2			N/A	N/A	N/A	Yes	Dev	Mon
Mirima	PWR	Kenya	100	3.1			N/A	N/A	N/A	Yes	Dev	Mon/Bas
SKK	SKKH	RSA	87	14.4	61.89	70	2.7	26	6.28	No	Dev	Mon

5.2.1 REE Resource

Several new deposits have been discovered worldwide, including some in Africa. It is important to understand the resources mapped by the companies pursuing those deposits. By comparing REE resources in Africa against players in other parts of the world, a clear picture of Africa's potential position can be assessed and the optimal strategy to develop those resources can be determined.

FIGURE 23: REE Resource for selected world deposits, 2019.

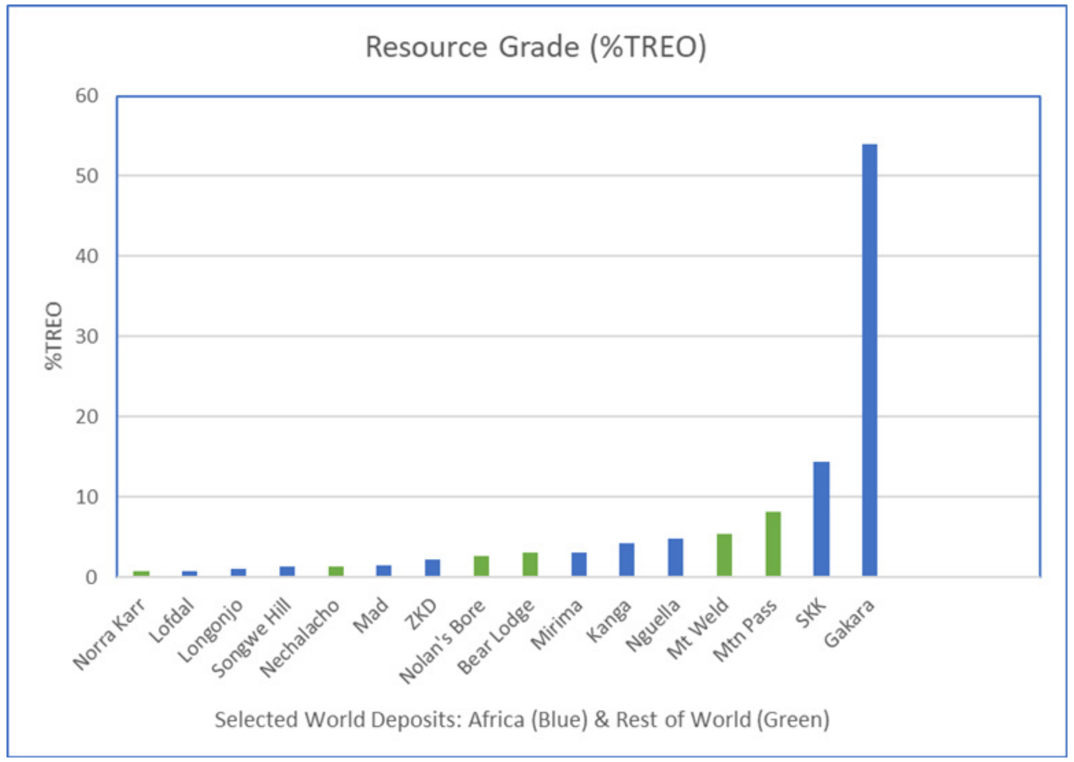


The Logonjo, ZKD and Nguella deposits in Angola, South Africa and Tanzania have REE resources that are reasonably large, ranging from about half a million to about a million REO resource, but most of the deposits in Africa, (indicated in blue in Figure 23) are at the smaller end of the world REE resources discovered so far. This should not be misconstrued as an assessment of Africa's potential against the rest of the world but rather a significant opportunity for further development. Exploration in Africa only started recently and few deposits have yet been fully explored, hence the small-sized resources compared to the developed world, which have been more thoroughly explored to their last mineralization. Most important on the listed resources is the fact that SKK, with the smallest resource size, has a definitive feasibility study showing positive results and profitability as described earlier. This is the potential Africa is beginning to realize: most of its REE deposits have the potential for commercial exploitation just like the mineral resources in the developed world.

5.2.2 Grade of the REE Resource

REE resources have high variability in the content of the individual elements for each deposit. It is therefore important to provide an analysis of grade when determining REE resources. Many of the deposits in Africa are observed to retain higher Total Rare Earth Oxide (TREO) values when compared to other deposits in the rest of the world (Figure 24).

FIGURE 24: World resource grades (%TREO), 2019.



Many of the deposits in the Southern and Eastern parts of Africa have higher TREO content compared to other deposits in the world, mainly due to their association with silicate minerals, an upside potential for the development of Africa's REE deposits.

5.2.3 REE Value Determination

The REE have slightly different properties and can be used in a variety of ways, which determines their demand and pricing on the market. Table 8 shows the individual REE prices as of November 2019.

Due to variations in the prices of the REE, the TREO percentage may not be the best way to determine the value embedded within an REE deposit. In some deposits, the TREO percentage can be high, but the value remains modest due to low proportions of CREOs in the TREO. This is because of the relative abundance of the elements at its geological formation whereas in many deposits, the least valuable LREE constitutes the largest proportion by mass of the resource.

TABLE 8: Rare Earth Element prices (Nov 2019)

Type	Name of Element	Symbol	Atomic Weight	Price in $ per kilo
LREE	Lanthanum	La	57	1.85
	Cerium	Ce	58	1.85
	Praseodymium	Pr	59	60
	Neodymium	Nd	60	44
HREE	Samarium	Sm	62	2
	Europium	Eu	63	40
	Gadolinium	Gd	64	25
	Terbium	Tb	65	700
	Dysprosium	Dy	66	350
	Holmium	Ho	67	50
	Erbium	Er	68	24
	Thulium	Tm	69	200
	Ytterbium	Yb	70	30
	Lutetium	Lu	71	650
	Yttrium	Y	39	3

Source: SKKH Information Memorandum

The price tag on each metal in a mineral resource is reflected in the valuation of the resource, therefore a new parameter taking into account the proportionate financial value of each REE in the resource could be a better way to evaluate an REE deposit as it shows the likely benefit an organization will receive from its investment. This 'value measure' is referred to as the 'basket price', being the sum of the proportions of the individual REOs in the product, multiplied by the price of the individual REOs (Equation (1)), in other words, this is an average value of a resource weighted against the individual value contributions of each element:

$$\text{Basket Price} = X_1 + X_2 + \ldots\ldots\ldots\ldots + X_{15} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

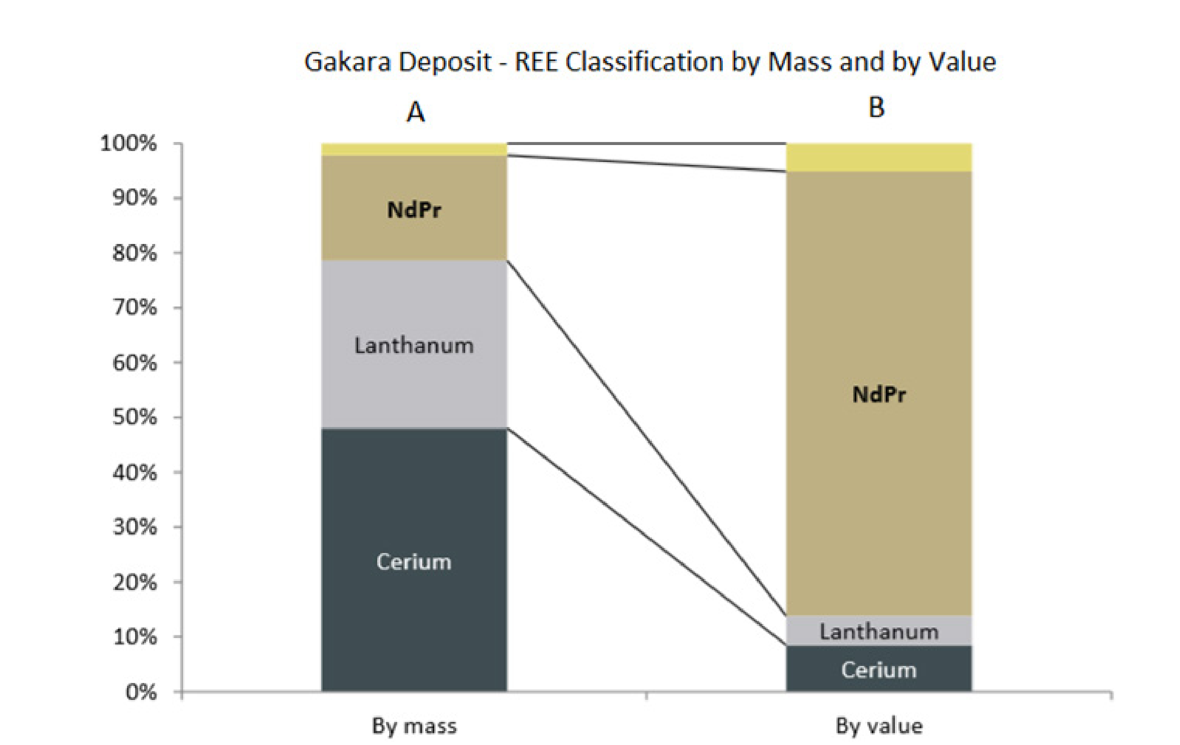
Where Xi = (Content of ore in REE i)/(REO) X (Price of REE i)

(e.g. For terbium, $Xi = X_{Tb} = (Tb_4O_7(t))/(TREO(t)) \times (\$500/kg)$*)*

These resource evaluation parameters are important when developing the value chain. At the early exploration stage, using REO and TREO content as a classification tool is very helpful as it provides a clear picture of the nature of a REE deposit but as the development of the resource progresses, it is imperative that parameters depicting the likely future economic benefit, are used. This is where the classification using a basket price takes over from the use of

TREO, as it can be used to derive economic parameters like revenue, which is subsequently used in the cash flow and profitability analysis of the value chain. A typical example is Rainbow's Gakara deposit with lanthanum and cerium constituting the highest percentage by mass (about 80%), whereas neodymium (Nd) and praseodymium (Pr) (commonly referred to as NdPr), with primary use in the manufacture of permanent magnets, account for more than 80% of the value (Figure 25) and yet in weight terms they constitute 19.5% of the TREOs. This implies in terms of TREO, the grade of the resource is biased towards the less valuable La and Ce, but in terms of value, the REE basket price tends to lean towards NdPr.

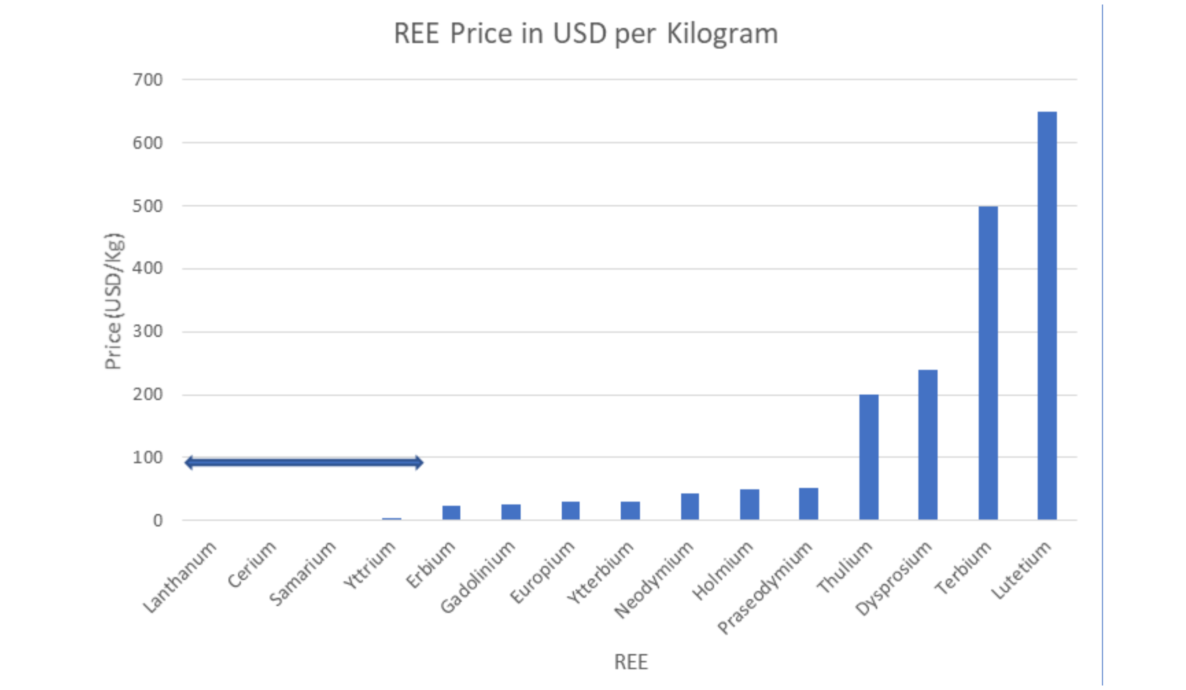
FIGURE 25: Gakara deposit classified by Mass (A) and by Value (B).



Source: Rainbow Rare Earth [10]

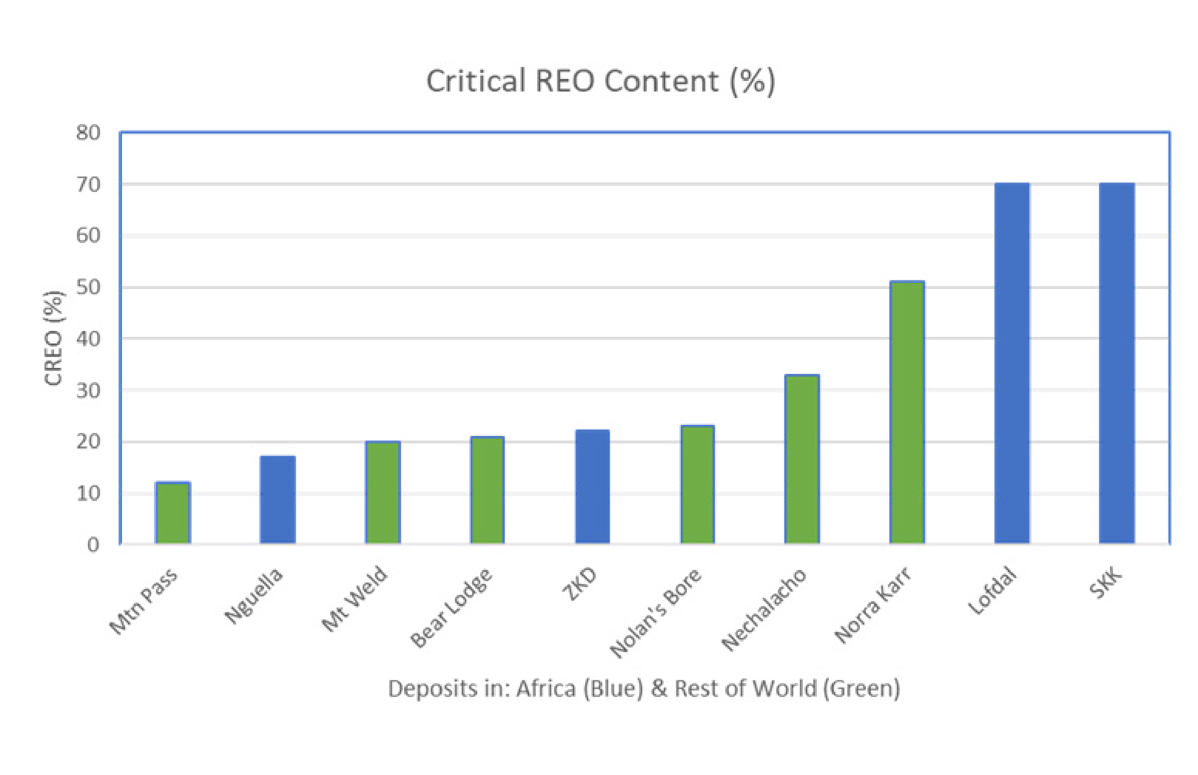
It has been demonstrated that when classified according to their atomic number and weight against price (Figures 8,23), the heavy REE (HREE) fetch higher prices than the light REE (LREE). It is therefore important to understand the composition of a deposit when evaluating its resource. A predominance of the LREE may render a project uneconomic to develop into production because of the lower prices the resource will fetch on the market even if the TREO and tonnage are determined to be high. When plotted in order of value (Figure 26), three distinct classes of value are observable: a) thulium to lutetium at market prices from $200/Kg upwards; b) erbium to praseodymium with price values ranging from $20 - 60/Kg, and c) lanthanum to yttrium with market values of up to $3.00/Kg.

FIGURE 26: Individual REE prices as of November 2019



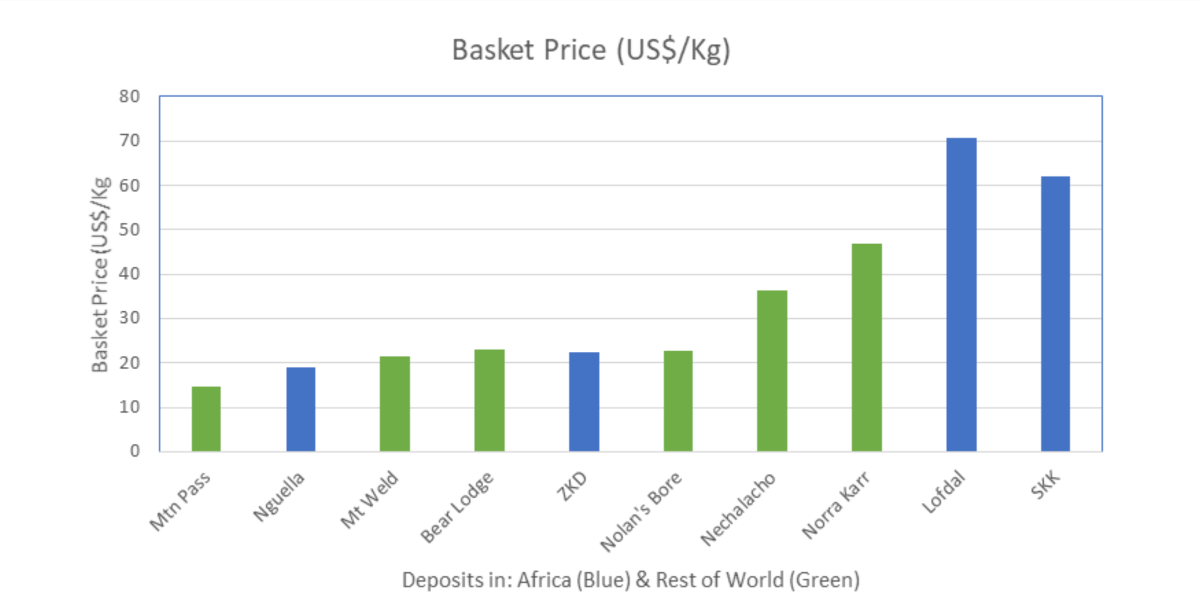
There are a few of the LREE group fetching good prices and equally several of the HREE not performing well on the market. It is because of these variations that a new grading system has been put in place for use in conjunction with the classifications above. The so-called "Critical Rare Earth Elements" (CREE or CREO when accounting for the valuable/commercial product only) comprising of neodymium (Nd), europium (Eu), terbium (Tb), dysprosium (Dy) and yttrium (Y), are increasingly becoming important in any business involving REE. They have particular use in high tech industries including green projects/low carbon future, electronics, defence, and other specialty industries. As such, their demand is high and so therefore is their value on the market. It is noteworthy that four of these elements are HREE and one of them is a LREE. These are elements predicted to remain buoyant in the future and therefore are key in determining viability of an REE project. Many of the deposits in Africa have proven their worth as they contain higher proportions of the CREO than other deposits elsewhere . Figure 27 is a plot of selected deposits against their CREO values.

FIGURE 27: Content of Critical REE in Selected World Deposits



Two of the deposits, Lofdal in Namibia and SKK in South Africa, are top of the selection showing high CREO content, an upside potential for REE value chain development in Africa as its deposits are capable of meeting the right quality of REE on the market (Figure 27). With an REO content leaning towards the CREO, it is not surprising to see better basket prices for these deposits when compared to other deposits on the selection (Figure 28).

FIGURE 28: Basket Prices for selected deposits, 2019



Basket price is the main economic driver of the viability of a REE project as REE commodities are sold on a basket price basis, which determines expected revenues when planning and optimizing the life of a mine. It is important for a REE deposit to have grades biased towards the so-called critical REE to achieve a better basket price.

Assuming operational efficiency is the same for various projects, capex, opex and profitability should show some semblance to the sizes of the projects. Table 9 shows these parameters for the three projects under development in Africa.

TABLE 9: Economic parameters for the three African deposits under development

Deposit	LoM (Years)	TREO Production (T/Y)	Capex (X US$106)	Opex($/Kg)	NPV (X US$$10^6$)
ZKD	20	20,000	910	11.9	**3,500**
SKK	10	2,700	26	6.28	**65**
Gakara	10	10,000	10	1.53	**52**

Two of the projects, Gakara and SKK, are optimized for 10 years, producing 10,000t/y and 2,700t/y of REO, respectively. It is interesting to note that Gakara, on the contrary, has a much lower capex than SKK. This could be attributed to the differences in mining methods being used. Another possibility could be that Gakara is using free dig and handcobbing with minimal use of heavy equipment and explosives. SKK's annual tonnage is 2,700 compared to Gakara's 10,000 but their net present values (NPVs) are comparable. This is another demonstration of the benefits of value addition. By processing a step further, SKK has an NPV higher than that of Gakara yet SKK produces almost a quarter of Gakara's tonnage, and their basket prices are comparable.

ZKD is in a league of its own but it should be noted that whilst it is a relatively high tonnage project, its large value could also be a direct effect of the value addition driven by Frontier's investment in the whole value chain of the REE.

5.3 Regional approach to the development of REE value chain

Like any other mineral development, the REE business has its own constraints. Whilst some could be addressed at the national level, others may benefit more from a regional approach. For instance, the issue of developing markets for REE products and the generation of geological data and information may benefit from a regional approach. Also, the prevailing policy frameworks in most African countries are not tailored specifically for REE mining but generally to other metal commodities.

Furthermore, REE and its beneficiated products are internationally traded with attendant high supply risks. Policy frameworks globally are tailored towards protecting the economic and social interests of different nations. Globally, such frameworks revolve mainly around production (exploration and exploitation), research and development, legislation relating to storage and stockpiling, defense interests and transparency. These policy options in the developed economies, especially the USA and China as the major consumers of rare earths, seek to rejuvenate and control the exploration and exploitation of rare earths worldwide. This policy is also tailored toward future control of emerging producers and markets for value added products of REE minerals, like Africa. Therefore, it is extremely important for Africa to cooperate in the development of the REEs in order to have a common strategy and an influential voice in the global REE landscape. The following policy measures are worth due consideration.

5.3.1 Proposed Policy Measures

(a) Create markets for Africa's REE Products

In the initial stages of REE development, Africa needs industry players who can bridge the gap to major customers until such a time that Africa will be in a position to meet that demand. Making JVs and PPPs with existing companies will be a good starting point. Market creation will be a gradual process that is also directly influenced by the growth rate of the continent. With time, Africa can start to promote value addition to the industry beyond the production of concentrate, and thereafter venture into further processing to produce the final saleable products, as well as developing its own consumer industry. To transition from a foreign to local market, it will require a combined effort among Africa's member states. AfCFTA has a significant role to play to support the establishment and strengthening of REE markets in Africa through a well-developed strategy and action plan.

(b) Promoting National and Regional Mineral Exploration

Exploration to date indicates that REE deposits are varied. Some deposits are sufficiently large to merit their own integrated process plants encompassing the whole value chain, but others are too small for a localized value chain to be established. The scale of demand envisioned requires Africa to create a strategy to develop its resources. To achieve industrialization goals, African countries should pool their resources and work as one economy, or at least operate within the boundaries of their regional communities such as ECOWAS, SADC, and EAC. Regional cooperation can create a sustaining environment with the potential for significant capital and human resource investment while at the same time creating a market for the products. The starting point is to ensure the availability of a regional geological database that transcends political boundaries which would enable the geological potential for hosting mineral deposits (including REE minerals) to be marketed. This can be achieved by countries collaborating to compile preliminary geological information and enable regional geological studies to provide data to prospective investors about the likely locations of minerals. Geological databases and remote sensing equipment can be collectively acquired by member states. With developed countries looking for new frontiers for REE supply, development finance institutions could also be potential sources of funding for regional REE exploration, in addition to the member states' own investments. As well as providing the groundwork for investment in exploration, impediments to investment should be removed: mining policies should be investor friendly and should be ratified among member states.

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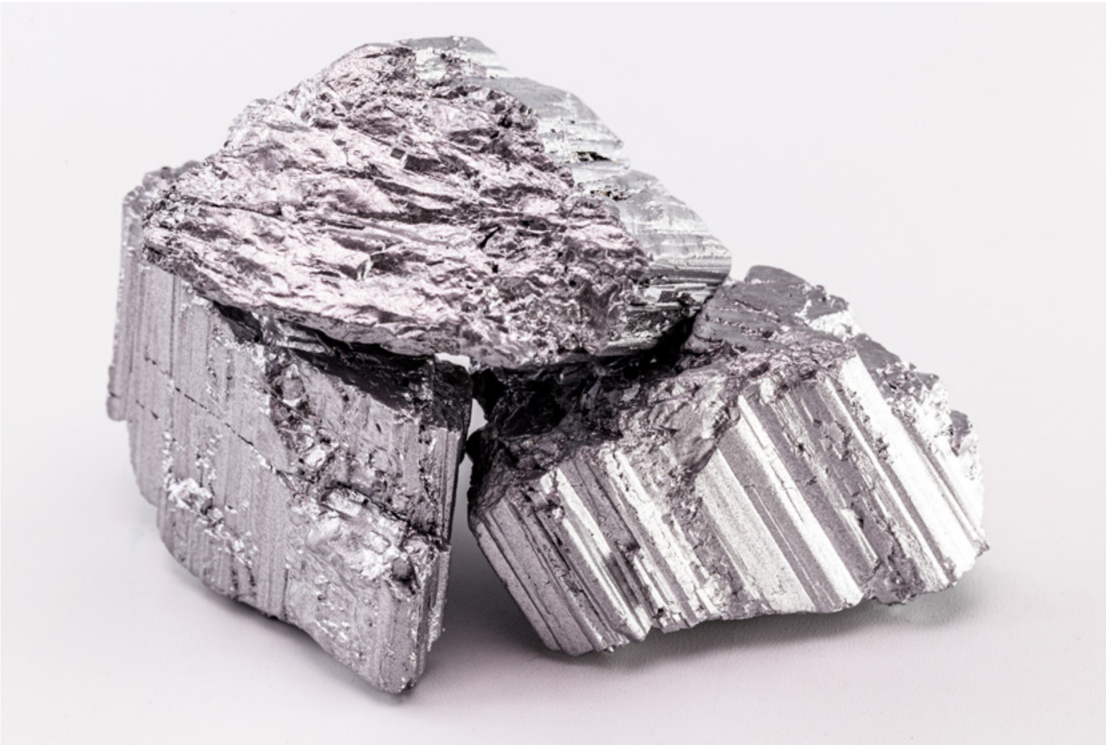
For member states to maximize benefits from the development of the value chain, a strategy to develop local service providers should also be considered. Most of the costs during exploration relate to drilling, sample assaying, hospitality services, and hiring expert skills and experience. As a parallel strategy, Africa should look at strengthening the existing service facilities to ensure that they can handle this additional potential service work. One example of how this could work for both partners and countries is that by strengthening the assay laboratories in the respective regional communities, unnecessary expenses incurred on exporting samples for geochemical assaying at laboratories abroad can be curtailed. This provides a form of value addition from savings in foreign currency needed for external assay labs as well as the complexity of shopping and time delays, while at the same time creating employment and tax revenue to the government of the country hosting the laboratory facilities. In similar ways, other service delivery areas as varied as drilling, geophysical surveys, and catering should be factored into the strategy for maximum country and regional benefit which would also prove attractive to partners.

(c) National and Regional Strategies for Optimizing the Value Chain

While an integrated mine and plant capable of processing the REE metal from mining to final product is desirable for capturing the maximum added value, its feasibility is dependent on the size of the deposit and the economies of scale. Big deposits can be optimized to produce sufficient concentrate to supply captive process plants at a profit, whereas for small deposits, a mine comprising of ore extraction and beneficiation plant up to concentrate production could prove to be more economic than integrating all process stages. This calls for synergies among countries to enable a more economic regional approach to develop smaller REE deposits. Small mines with little capacity to sustain the whole value chain can pool resources to create a regional processing plant. While a single small mine could not sustain the entire processing chain, several mines feeding into a regional plant could unlock economic benefit for both the mining operations and the regional plant. A regional plant can ensure the availability of a ready market and therefore profitability for small to medium-sized mines from the sale of their concentrate and, at the same time, the plant could receive enough concentrate to optimize its scale to acceptable levels of profitability. If implemented well, regional communities can take advantage of this model to develop and financially assist indigenous miners to exploit the smaller deposits and sell their concentrates to a regional process plant, probably financed by funds from the regional states, and leave the larger deposits to big corporations



with the financial and technical muscle to develop them sustainably.

For such value chain development transcending political boundaries, it is essential for governments of the countries involved to create a common enabling environment that facilitates regional-scale mining and beneficiation to achieve technical economies of scale. This highlights the need for common regional economic community (REC) wide polices to facilitate these types of operations. Governments should have in place clear policies on the major economic parameters effecting the viability of a mining venture like tax rates, royalties, local content, procurement, import and export duties, environmental management, and licencing as these factors have a strong bearing on the feasibility study and therefore the subsequent funding of the development. To attract greater benefit from the investment, regional countries should create synergies and harmonize mining policies that encourage investment for the benefit of both the investors and the nations and reduce any impediments to investment.

Countries in possible regional groupings can leverage efforts and establish vertically integrated metallurgical plants with the best levers for success. The East African Community (EAC) and Southern Africa Development Community (SADC) can deliver a common policy that enables integrated REE operations to be successful. Already we see several green energy projects taking place in the regions which would have the potential for significant consumption of the locally produced REE. Examples include the electric vehicle manufacturing plant in Uganda, and wind farms in Kenya and South Africa for green energy. These industries can potentially absorb a significant amount of REE and eventually some African states may go beyond REE production into production of end-user goods, like magnets for wind farms or batteries for electric and hybrid vehicles with immense benefits to the country or region.

(d) Develop Smart Partnerships with Fully REE Integrated Companies

Whilst regional and continental cooperation is important, there is also a need to develop such synergies with developed countries. China provides a useful case study to learn how it managed to successfully create an end-to-end value chain and achieve its goal of creating major employment opportunities. However, care should be taken to ensure the REE pricing system of China does not also put projects out of business. The western experience is also useful. These are the major markets in the short term so working with them is critical to better understand the quality specifications required by their thriving markets. They can also support the consolidation of the value chain as they have development capacity as well as high levels of skills and experience.

(e) Establish Market Intelligent Unit for Minerals at the Continental Level

To develop successful cooperation among African member states, policy vehicles ensuring proper coordination and collaboration between companies and country institutions as they develop REE are needed. One such policy vehicle can be the creation of a market intelligent unit (MIU) to coordinate functions like research and development (R&D), and analyse important themes such as: the potential impacts of supply disruption; the need for a more efficient regulatory framework for domestic minerals production and downstream processing development; the analysis of information in the global REE space; and the role of the African Union, the producing countries and the private sector. The policy should also involve the MIU in R&D on critical material challenges, including "end of life" recycling to help mitigate possible supply chain disruptions. The MIU could be created as a Unit of the Africa Minerals Development Centre (AMDC).

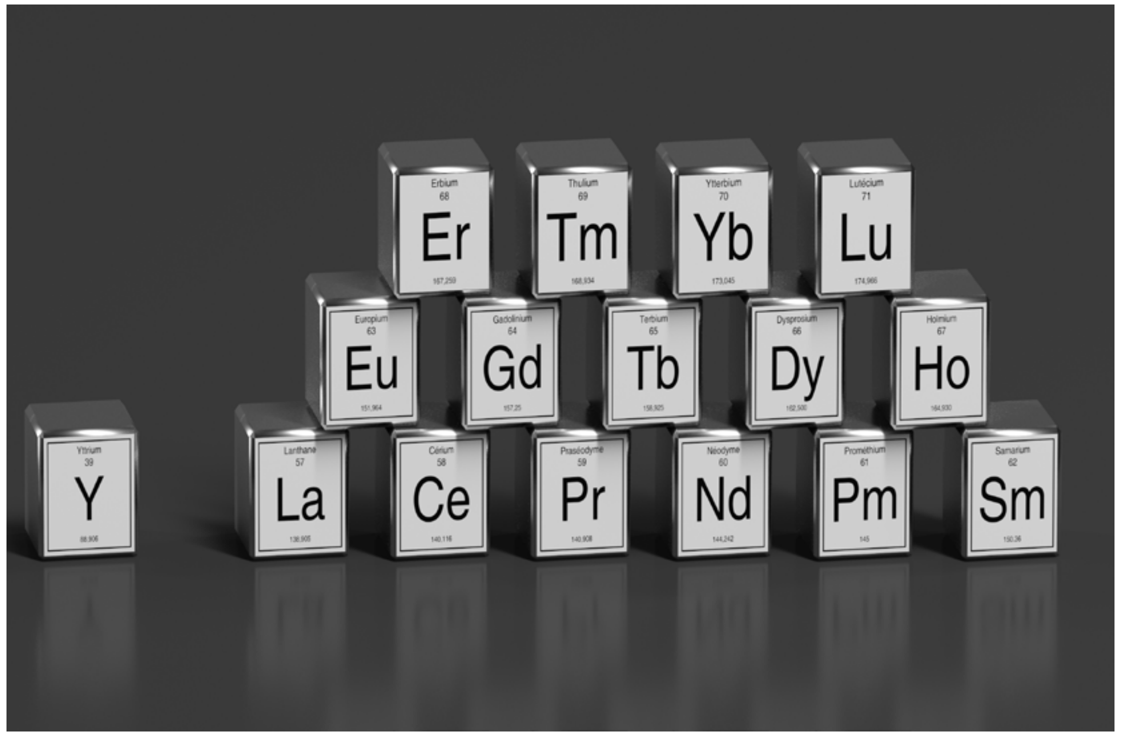
In subsequent years, this unit could be further funded to manage a materials science and engineering program and an energy innovation hub program to focus on these critical REE minerals. Additional world-leading added value could be developed by an applied magnet research program and an alternative motor design program designing motors without rare earth permanent magnets. These programs could be initiated as a matter of policy with advanced laboratories mainly in South Africa. In addition, conducting research on batteries for electric energy storage and substitutes for rare earth magnets should be included in the policy framework.

(f) Strengthen National Geological Surveys to Establish Mineral Information Systems

The policy framework will encourage the establishment of national, regional and continental REE minerals information centres housed within the national geological surveys of producing and potentially endowed countries and the African Minerals Development Centre (AMDC). This information network should provide an annual summary of rare earth activity and a well-articulated mineral commodities report, like jurisdictions like the US through the US Geological Survey (USGS) or the UK through the British Geological Survey (BGS). The policy would also periodically publish mineral resource assessments for government and would be investors. The existing African continental industrial policy should be reviewed to include provision for the rare earth mineral supply chain.

(g) Establish Inter-governmental Working Group on Critical Minerals

The AU should facilitate the formation of an Interagency and inter-governmental



working group on critical and strategic minerals, (including REE), and their supply chains. The working group should include representatives from key government departments such as energy, defense, the interior, commerce, environmental protection, foreign affairs, Justice, and trade. The group's focus would be to establish critical mineral prioritization and early warning mechanism for shortfalls, to monitor inter-governmental cooperation with the MIU, regional R&D priorities, to review domestic and global policies relating to critical and strategic minerals (such as recycling, and trade) and to ensure the transparency of information.

(h) Promote Artisanal and Small-Scale Mining of REE

Where possible, based on issues such as the geological occurrence, African countries should develop appropriate regulations and legislation for the development of REE on a small-scale mining basis. The ASMs could for example provide feedstock in the form of ores to established large scale companies for value addition and regulations can be put in place to deliver improvements in the safety, equality and ethical practices in small mines.

(i) Develop Appropriate Skills for the REE Industry

A mining operation employs a range of skills sets including: geologists, mining engineers, metallurgists, chemical, mechanical, electrical, civil, and electronic engineers; fitters, electricians, plumbers, welders, and functional specialists like accountants, information technologists, communications, finance, investor relations, human resources and legal. Most of these skills abound in Africa, however due to limited REE beneficiation in Africa, mineral processing skills in REE are limited. There is therefore the need to set up centres of excellence at the REC level to train students and professionals in the REE value chain, especially downstream processing into consumer goods and strategy. Other interventions in building skills could include study tours to foreign mining and learning institutions with similar REE operations in other parts of the world. Forward thinking would allow for planning ahead of industry need to enable these ready-to-deploy skilled personnel to join the REE value chain as it is established.

(j) Infrastructure and Logistics

Policy development necessary to provide better infrastructure and logistics are not just important for REE development but for the wider mining industry and other economic sectors within a country or region. Good infrastructure and logistics form a key element of economic development. Investors are generally attracted to jurisdictions with basic infrastructure in place and policies that facilitate the ease of executing business operations. In order to make the mining industry increasingly viable, required infrastructure such as railways, road, port, electricity and water needs to be provided either by the State or through a PPP. These activities need to be sequenced and linked to developments in business demand, helping production respond to demand and considering the technologies that will need to be put in place. Such infrastructure projects are long term and with a calculated prioritised approach the final infrastructure can be financed by phased economic activities in the various economic clusters. Many infrastructural developments should be hierarchical with policies promoting

road, rail, and air transport system at continental and regional level and linked with the same at country level. Infrastructure is a basic requirement for capital intensive projects like mining and authorities have a major to play in ensuring the environment is prepared for REE investment.

The first requirement to interest the private sector is to develop a feasibility study which demonstrates the viability and sustainability of REE deposits and details the development of integrated processing systems for value addition. REE are often sold as mineral concentrate and this is the most likely business scenario in the initial stages of Africa's market entry. Mineral concentrate is generally bulky and therefore requires good transportation from site to the port for export. Logistically there should be efficient logistical support for the movement of goods from one point to another with little red tape. Governments should ensure clearance at ports is as efficient as it can be for businesses.
In addition to transport and logistics, operations like mining require huge amounts of electricity. It is imperative that countries ensure reliable energy supply which often requires cooperation among regional countries to ensure the development of energy efficient frameworks. Water supply is another area that needs attention. Mining operations require the use of water and countries should ensure water is available in the event of an investment within any part of the country or region.

5.4 Summary

The foregoing policy measures need to be carried out within the context of the Africa Mining Vision, which calls for a transparent, equitable and optimal exploitation of Africa's mineral resources for sustained growth and socio-economic development.

A regional approach to developing the REE value chain through establishing common markets, conducting mineral exploration, enhancing the capacity of geological surveys to manage geological data and information, and developing critical skills for the REE sectr will be essential if Africa is to make strides in the global REE landscape.

Furthermore, it is extremely important for Africa to cooperate in developing REEs to have a common strategy and an influential voice in the global REE landscape. This is the only way Africa can address the competition adding value to for rare earths products worldwide.

06

Role of REE in Africa's Transition to a Low Carbon Future

This section looks at how Africa can consume its products to bolster economic development and at the same time play an important role in building a climate resilient and low carbon future. Potential markets in Africa in the short to intermediate term include green energy innovations to replace fossil fuel used to generate electricity, energy storage, and electronics engineering.

6.1 Green Energy

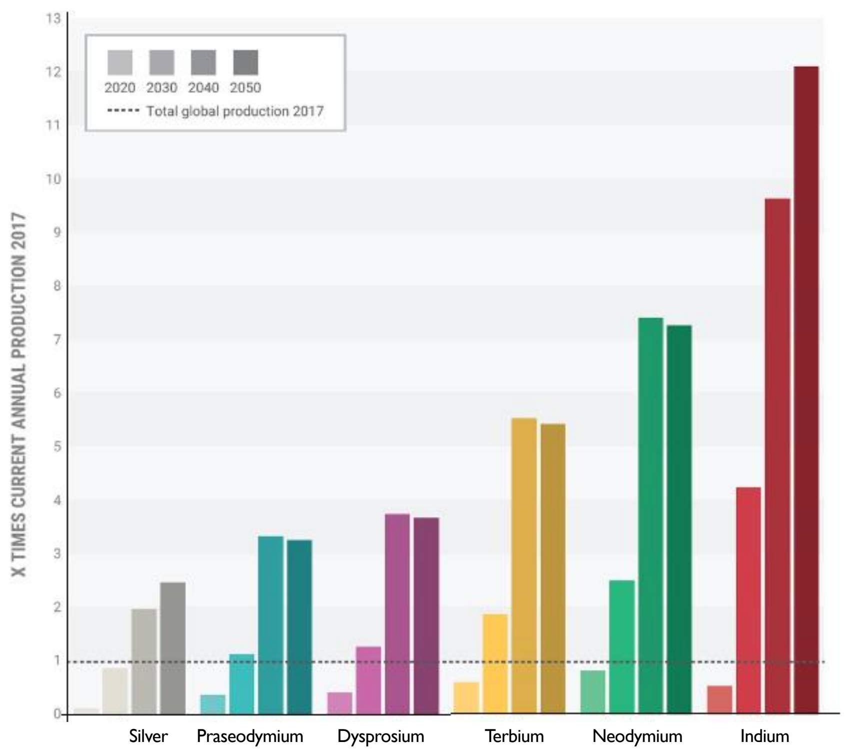
Many African countries are already putting in place policies that ensure the sustainable development of their economies, through agriculture, mining or manufacturing. This includes measures to ensure economic development activities to reduce environmental pollution. With the demand in REE anticipated in the foreseeable future, Africa will put pressure on its existing infrastructure and transport network necessitating expansion and redevelopment of infrastructure improvements. This development, and the mines and process plants themselves, will require an increased in energy production. Africa already has a serious energy deficit to meet its current economic needs implying new energy sources will have to be built. To cater for this energy deficit, and the energy requirements of new developments, Africa needs to increase its energy generation capacity, in a sustainable way . Now is the time for Africa to develop energy strategies that align with the utilization of its REE mineral resource.

At present, Africa has a mix of energy sources in use or under development including fossil fuels (thermal coal, and petroleum) and green energies (hydro, solar, wind and geothermal). With the potential for significant discoveries of REE reserves, Africa should pivot towards green energies, which will also become markets for its REE products . By establishing energy efficiency, Africa would have a twin benefit– creating a sustainable low carbon future, and creating a market for its REE natural resource, accompanied by economic benefits including employment creation, GDP growth, and savings on foreign currency. Presently, all the equipment and materials for the establishment of green energy projects are being imported at high cost and draining country reserves of scarce foreign currency. Developing the REE value chain to consumption can result in cheaper products (magnets and batteries) on the basis that other supply chain resources, like labor, can be sourced relatively more cheaply in Africa than in the developed world. Although solar panels hardly use REE, except for the thin film PV cells which use gallium (and indium) among other metals for their production, wind turbines requires large amounts of REE in turbines for the electrical generation drive.

Many African countries are already putting in place policies that ensure the sustainable development of their economies, through agriculture, mining or manufacturing.

For many interested parties in the green energy sector, a shadow looms over wind farms as concerns about supply chain restrictions have been raised in recent years due to China's monopolistic policies. Numerous reports published over the past decade have warned of an imminent rare earth crisis, and the manufacture of wind turbines, which contain rare-earth elements (REE) would be negatively impacted by these shortages. A new scientific study supported by the Dutch Ministry of Infrastructure warns that the renewable energy industry could face a fundamental obstacle of shortages in the supply of rare metals. To meet greenhouse gas emission reduction targets under the Paris Agreement, renewable energy production must scale up fast. This means that global production of several rare earth minerals used in solar panels and wind turbines—especially neodymium, terbium, indium, dysprosium, and praseodymium—must grow twelvefold by 2050 (Figure 29). In 2015, the EU's Joint Research Centre reported that 23% of turbines used permanent-magnet synchronous generators (PMSG) and forecasts show the number could reach 41% in 2020 and 72% in 2030, as investments in renewable energy continue to grow. But according to the new study by Dutch energy systems company Metabolic, the "current global supply of several critical metals is insufficient to transition to a renewable energy system."

FIGURE 29: Graph depicting global critical metal demand for wind and solar panels, between 2020 and 2050, compared with the 2017 level of annual metal production (2017 = 1).



Source: Metabolic

Market leaders like Vestas, Siemens Gamesa and General Electric need REE for permanent-magnet synchronous generators (PMSGs) employed in some wind turbines. These are the companies Africa should engage with as partners for the growth of its REE value chain. The European Union, in its quest to meet greenhouse gas emission reduction targets under the Paris Agreement is attempting to identify alternative REE supply sources to China and, through its development bank EBRD, is looking at avenues to widen its scope to include Africa as a supply source for its REE requirements. This presents a real opportunity.

Wind Energy in Africa

The leading African countries involved in wind power production are South Africa, Egypt, Kenya, Morocco, Ethiopia and Tunisia with a combined installed capacity of 6,673MW (Figure 30) as of 2019. Egypt and South Africa are expected to play a major role in the installation of new onshore wind capacity from 2019 to 2023, as each country is forecasted to add around 2 gigawatts of new onshore wind capacity in that period, a development indicative of sustained future growth of the REE market for wind turbine magnets. It is therefore prudent for Africa to strategize for development of the value chain down to end product production and consumption.

FIGURE 30: Africa installed Wind Power Capacity (in Megawatts

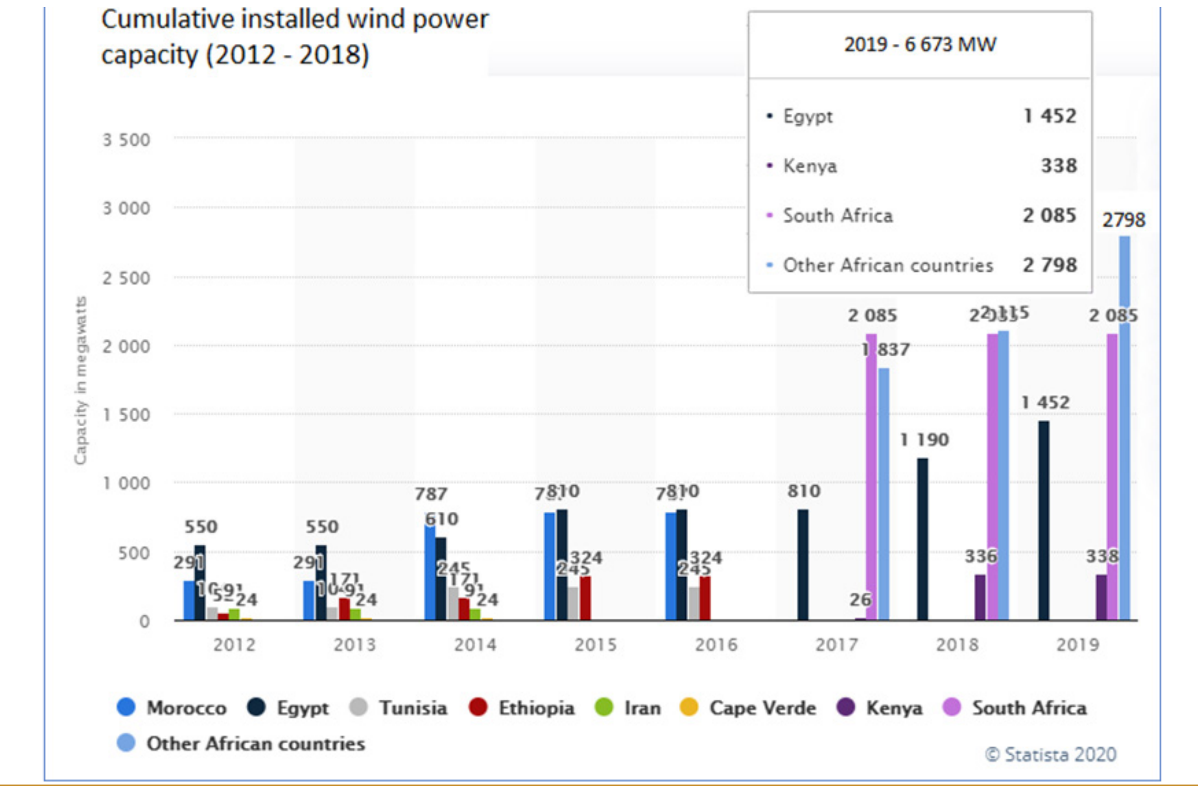


Figure 4 showed that Africa (and the Middle East) has generation capacity of 7GW, equivalent to 0.1% of the world's capacity. Figure 30 demonstrates Africa's wind generation capacity. In terms of REE consumption, the installed capacity approximates 1,400t of REE in direct drive turbine magnets at a consumption rate of a tonne of REE per 5MW turbine, yet Africa's potential power generation from wind turbines is estimated to be 110GW (M. Hafner et. al.)[1], equivalent to about 22,000t of REE. With the anticipated growth in renewable energy, the market is projected to be available for REE producers. This is in addition to the global wind power capacity additions expected to sit at an annual average of 77GW from 2020 to 2029, according to Wood Mackenzie[2], which, in terms of REE consumption, equates to an average increase in global REE consumption of 15,400t per year in wind turbine magnets alone, a clear indication of robust growth in the global REE market.

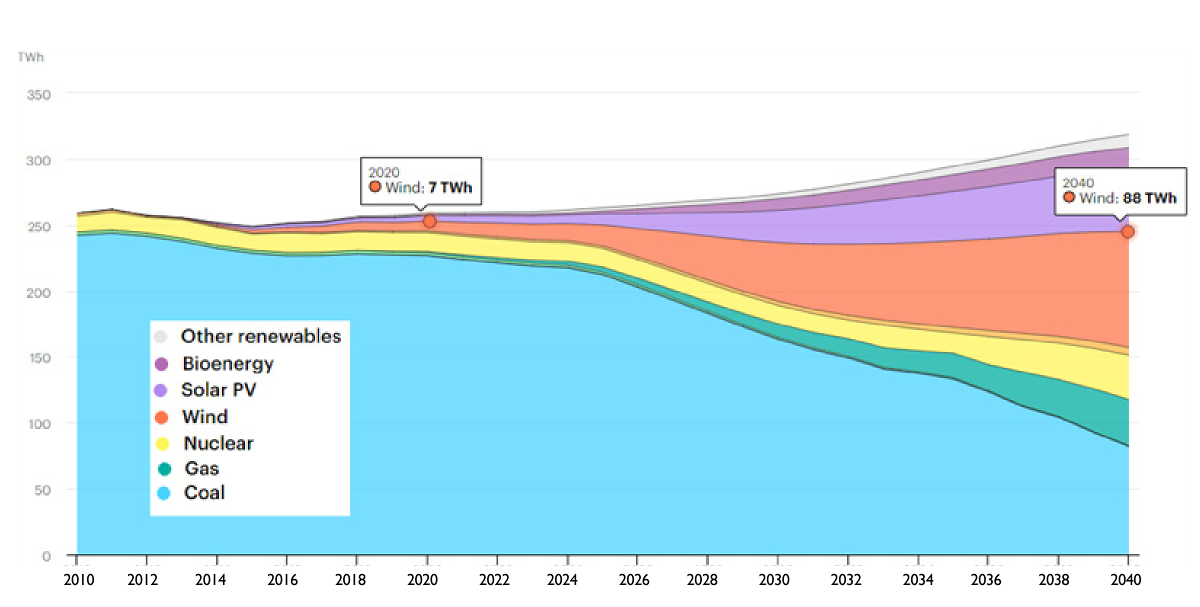
The demand for electricity in Africa is increasing with fossil fuel is the most used source of electricity production. The continent is therefore likely to witness a compounded effect when fossil fuel is gradually phased out and replaced by

[1] *https://link.springer.com/chapter/10.1007/978-3-319-92219-5_3#:~:text=African%20countries%20are%20gifted%20with,(African%20Development%20Bank%202017).*
[2] *https://www.woodmac.com/press-releases/global-wind-power-capacity-to-grow-by-112-over-next-10-years/#:~:text=Global%20wind%20power%20capacity%20additions,to%20the%20end%20of%20 2029.*

green energy options. South Africa alone is already experiencing high demand for green energy. With planned year-on-year electricity price increases of up

to 20% per annum, compounding to about 350% over the last decade (www.poweroptimal.com), and high carbon emissions from coal-produced electricity, South Africa should have a booming market for energy efficiency and renewable energy. That market trend is depicted in Figure 31 where green energies are expected to reduce fossil fuel consumption by more than half by 2040, with wind energy taking a significant share of the energy market. Wind turbines, which consume most of the REE in power magnets are expected to rise from the current 7TWh to 88TWh by 2040, which approximate to an increment of 1,157% in consumption. This is indicative of a huge market for REE in South Africa alone.

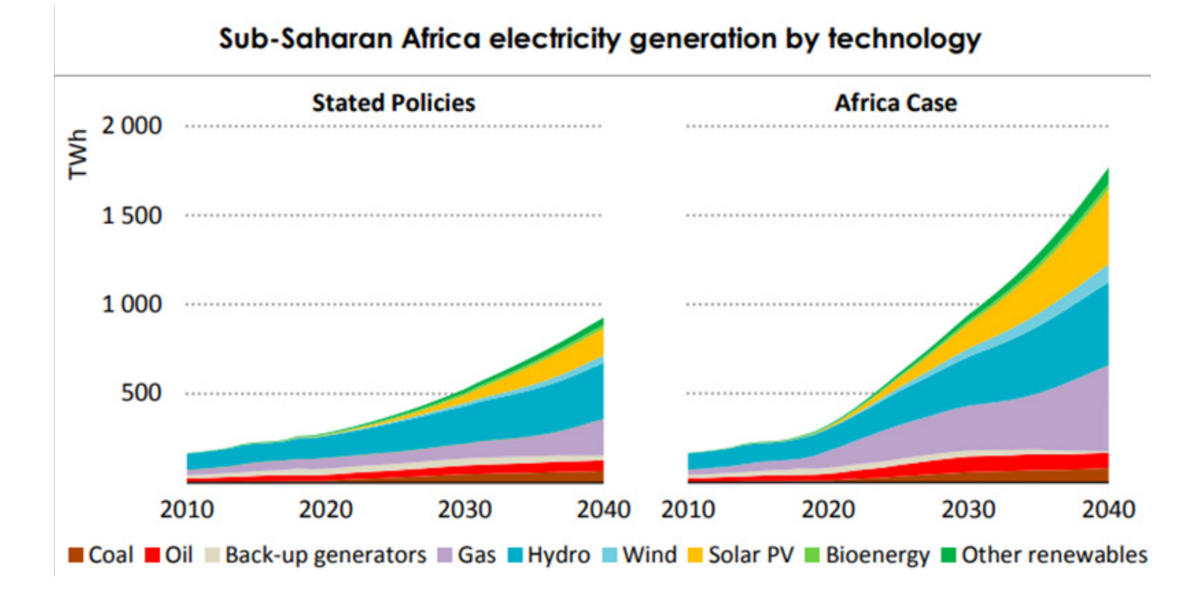
FIGURE 31: South Africa energy generation forecast by technology.



Source: IEA, 2020

An alternative interpretation of Figure 31 would imply that South Africa currently uses about 200t of REE to generate 7TWh of electricity, which is expected to rise to about 2,500t of REE to meet the planned wind power output of 88TWh, assuming a consumption rate of about a tonne of REE per 5MW direct drive turbine. According to the International Energy Agency (IEA), sub-Saharan Africa is projected to generate in excess of 500TWh from wind turbines by 2040 (Figure 32), requiring more than 15,000t of REE. The REE consumption would easily surpass 20,000t when North Africa is incorporated in the equation.

FIGURE 32: Electricity generation by technology in sub-Saharan Africa



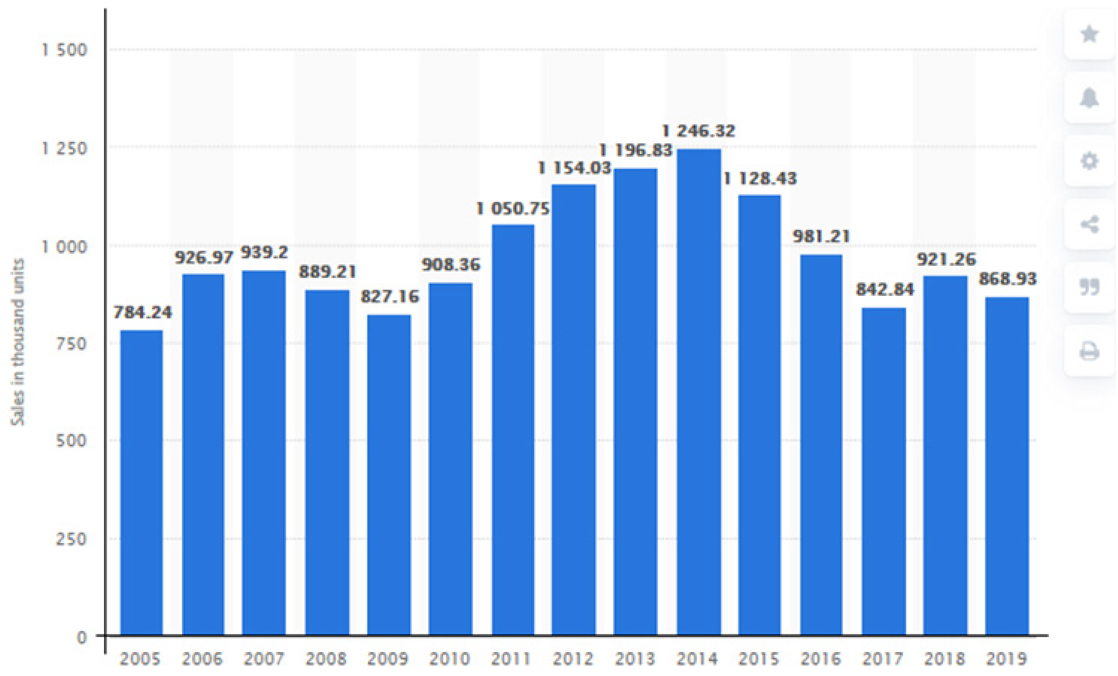
Source: IEA, 2020

**NB: The stated policies scenario reflects IEA's measured assessment of today's policy frameworks and plans, taking into account the regulatory, institutional, infrastructure and financial circumstances that shape the prospects for their implementation against the Africa Case, which is built on the premise of Agenda 2063, the continent's inclusive and sustainable vision for accelerated economic and industrial development. Faster economic expansion is accompanied by the full achievement of key Sustainable Development Goals by 2030. These include full access to electricity and clean cooking and a significant reduction in premature deaths related to pollution.*

6.2 Electric Vehicles

Another opportunity for Africa is in the manufacture of electric vehicles. Now is the time to invest in electric cars as ICE vehicles will soon become history as the world makes the move to reduce its environmental impact. The World's transition to a low carbon future will revolutionize the automobile industry and the supply of raw material like REE for EV manufacture. It is estimated that Africa has almost 3 million registered cars, and data from Statista indicates almost a million new cars were sold in Africa (Figure 33). Assuming most of the cars in Africa will become electric, a million EV sales per year at an REE consumption rate of 2kg/unit, implies the need to use 2 million kg (2,000t) of REE. The Steenkampskraal (SKK) mine in South Africa could be optimized to produce 2,700t/y and could be (theoretically) dedicated to supplying EV manufacturing in Africa, thus creating an end-to-end REE supply chain for the continent.

FIGURE 33: Passenger car sales in Africa between 2005 and 2019.



Several African countries are already developing innovations for their own for 'home grown' vehicle brands, with some of their EV models under trial for the market. Below is a list of countries that have developed their own vehicle brands:

6.2.1 Kiira Motors, Uganda

Kiira Motors Corporation[3] (KMC) is a state enterprise established to champion value addition in the domestic automotive industry for job creation and diversification of the Ugandan economy as a part of Uganda's 'Vision 2040'. The equity partners are the government of Uganda represented by the ministry of science, technology and innovation (96%) and Makerere University (4%). The company manufactures hybrid vehicles[4] and has a pipeline strategy to manufacture a 100% electric vehicle in the near future with both models requiring REE products like batteries and magnets. Uganda has moved a step closer to creating a market to produce REE consumer products, thus taking the value chain beyond the REE supply chain.

The government of Uganda expects that by assembling cars partnering with experienced manufacturers it can step by step improve the domestic value added by exploring linkages in tangential industries like mining but including agriculture, industry and ICT to enable opportunities to develop for its people to participate in local content.

3 *http://www.kiiramotors.com/*
4 *http://www.kiiramotors.com/kiira-ev-smack/*

6.2.2 Kantanka Automobile Company (KAC) Ltd. Ghana

KAC Ltd in Ghana specializes in the manufacturing of on and off-road vehicles meeting the challenging nature of African terrain. Its objective is to manufacture and assemble cars with higher added value, expand OEM (Original Equipment Manufacturer) expertise and create a niche market with new types of vehicles that give value for money to medium and lower income earners in Ghana, sub-Saharan Africa and the rest of Africa.

6.2.3 Innoson Vehicles, Nigeria

Innoson is a Nigerian company in the business of manufacturing durable and affordable vehicles for Africa with brand new automobiles selling at affordable prices for the same comfort as any imported vehicle.

6.2.4 Mobius Motors, Kenya

Mobius designs, manufactures and sells vehicles built specifically for the African mass market. Mobius is not just building vehicles suited to local demand, but a transport-business platform that empowers local entrepreneurs to run profitable transportation services to end-users in their communities. Mobius' vision is to become the mass-market car of Africa and connect millions of people across the continent.

6.3 Electronics and other uses

The high-tech electronics industry is ever evolving and growing but remains anchored on REE and other critical metals. The unique properties of rare earth elements make them well suited for use in a variety of products, including cell phones, batteries, loudspeakers, lights, and magnets. In addition, they are often key elements used in the creation of components used in objects, such as light-emitting diodes (LEDs), fiber optics, compact fluorescent lights, and are used as catalysts, phosphors, and polishing compounds for air pollution control, illuminated screens on electronic devices, and the polishing of optical-quality glass. Some of the rare-earth metals commonly used in electronics include lanthanum, cerium, neodymium, samarium, europium, terbium, and dysprosium. The demand for rare earths is expected to increase rapidly, driven by an increase in the use and production of items that are manufactured using rare earths. For example, in 1998, mobile telephones, which have batteries that require rare earth elements, were used by just 5.3% of the global population, according to international telecommunications industry data. By 2017, the penetration rate of mobile phones worldwide had reached 103.4% (exceeding 100% due to ownership of multiple devices).

REEs are also highly in demand in the military and the drone industries. The market size for the drone industry is forecasted to rise from $14.1 billion in 2018 to $43.1 billion in 2024 and in the military, not only are neodymium and praseodymium used in many advanced military applications, but the fact that the whole of the western world is reliant on China for supplies of critical parts for their military requirements make the existing supply chain a highly risk process.

6.4 Summary

Whatever amount of REE Africa produces, the biggest market remians in the green energies sector implying Africa can play a significant role in creating a low carbon future. With time, the market and demand are expected to expand. In the meantime, Africa will be gaining the skills and experience to advance the processes of value addition to the next level, to create the environment to manufacture end products and become a supplier as well as consumer of its own products. This is what Africa needs – to develop the full value chain so it can create job opportunities for its growing population. The model replicates the Chinese. In the 1970s, China exported only concentrates of rare earths, while by the end of 1990s it began producing magnets, phosphors and polishing powders (Mancheri, 2015). Currently, China is largest RRE producer in the world and the only country that has developed a complete value chain – comprising hundreds of independent companies dedicated to rare earth research and production, each providing highly differentiated technologies, processing, formulation, or component-specific applications.

Kiira Motors of Uganda is constructing a manufacturing plant for EVs after successful prototyping. While the other manufacturers are producing ICE brands, the natural route of migration is already defined. They will transition to manufacture of electric vehicles once policies prohibiting use of fossil fuel come into play. By then, they would require country or regional support with the manufacture of REE bearing parts for their businesses. The wind and solar powered car might appear far-fetched, but such innovative ideas should be supported as they, in many cases, become forerunners of a successful innovation leading to an invention. AT the same time, these companies are already gaining the know-how of the automotive industry and will eventually transition to EV manufacturing like the other players in the industry.

All these developments are indicative of the potential for Africa to seriously consider end-to-end value chain development, not only for REE but all the other major minerals being mined on the continent. There should be support at national, regional and AU level in order to harmonize the system and create synergies among member states.

The next chapter discusses the constraints associated with value chain development of REE in Africa.

07

Constraints Associated with REE Value Chain Development

In any enterprise, there are risks associated with the development of the business. It is important to analyze such risks and develop appropriate mitigation measures to minimize the chances of failure. The REE value chain has its own challenges, and it is important to pre-empt any foreseen risks and include mitigation measures.

7.1 General and Industry Specific Risks

Market conditions, particularly those affecting resource companies, may affect the value of a project, regardless of its operating performance. The operation could be affected by unforeseen events outside its control, including natural disasters, political unrest, government legislation or policy. General economic conditions affect commodity prices, exchange rates, interest and inflation rates and movements in these rates could impact a company's profit margins and on the cost of raising and maintaining debt finance. The financial markets' perceptions of resource companies could change and affect a company's ability to raise funds. These are common risks to any mining operation and they can also affect the REE value chain if they are not properly addressed prior to project implementation.

Price fluctuations are a major risk throughout the commodities industry. Price can vary according to demand or new technologies could emerge which may not require the use of REE. For example, the US is looking for alternative sources of REE supply to China as well as alternative technologies to REE for its future industrial needs. The US Department of Energy's advanced research fund (ARPA-E), is being used by General Electric Global Research (GE) to develop next-generation permanent magnets with a lower content of critical rare earth materials. For the $2.2 million project, GE is developing bulk nanostructured magnetic materials with a dramatic increase in performance relative to state-of-the-art magnets. These new magnets will increase the efficiency and power density of electric machines while decreasing dependence on rare earth minerals. If successful, this project will lead to technologies for scaled manufacturing of low-cost, reduced rare earth-content, high-energy-density permanent magnets. It is imperative that Africa keeps an eye on technological trends and supply and demand forecasts to avoid being caught in an obsolete business investment.

a. Skills Development

Africa has a critical shortage of the key skills required in developing supply chains like the REE. Mining might not be much of a skills shortage risk, but the processing part of the industry can be a challenge for many operations. Skills development should be planned and implemented ahead of supply chain development. Ways to achieve this might include synergies with countries and or companies with experience in REE processing (e.g., China and Lynas respectively), and tertiary institutions with the expertise in fields such as materials, chemical and metallurgical engineering.

b. Transport logistics

The lack of suitable road, rail and water transport systems can have a serious impact on the development of the REE value chain and getting the commodity to market. There is a need to revamp the transport systems in many parts of Africa, and this can be done more efficiently if it is planned at a regional scale.

7.2 Project Specific Risks

These are risks associated with the development of a business unit like mining and beneficiation.

a. Resource and Reserve Estimates

Mineral resource and the mineral reserve estimates are expressions of judgement based on knowledge, experience and industry practice. These estimates may be materially affected by geological, mining, metallurgical, infrastructure and other relevant factors. It cannot always be guaranteed that the ore reserves will be brought into profitable production. Also, rare earth elements' prices vary according to uses and are prone to fluctuation which can affect the REE basket price and therefore value of an REE resource and reserve.

b. Public Acceptance of Rare Earth Elements

The unique characteristics of rare earths, its location and the conditions of mining it, imply that the industry may be subject to public scrutiny about risks that could have an adverse impact on the demand for rare earths. Rare earth mining is frequently associated with radioactive by-products like thorium and uranium. Concern about these radioactive by-products could affect perceptions about the project development. An example is Lynas Corp which was met with resistance from local communities when it was developing its process plant in Malaysia. Stakeholders feared contamination from toxic waste from the process plant. Other issues of equity and use of child labor associated with artisanal and small-holder mining practices, particularly in DRC, have also been the subject of concern from user markets.

7.3 Entry Barriers to Exploration and Mining of REE

In addition to the risks described above, there are additional barriers that make it difficult for African entrepreneurs to enter the business of mining in general, let alone REE mining, which is currently monopolized by China. The following are key entry barriers to the industry sector:

a. The REE Market in Africa

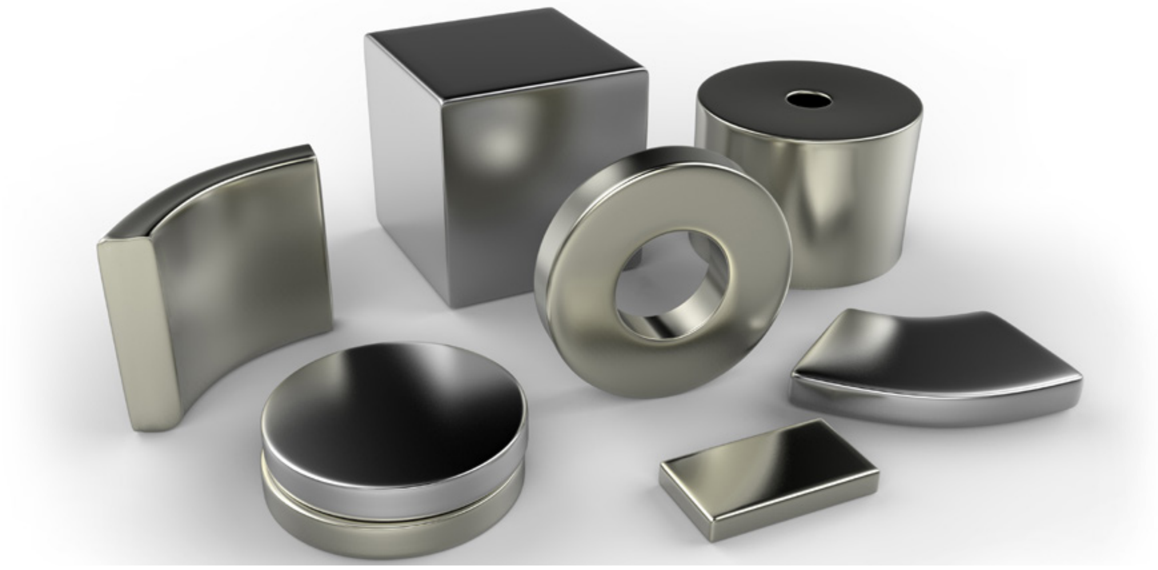
The fact that all high-tech consumer goods using REE are manufactured outside of Africa makes it difficult to develop the industry in Africa, particularly for African entrepreneurs. The consumer market for REE also lies with China and the western world. It is logical that companies first look for mineral deposits in regions closer to the market. The main market for REE products is in China and it is the largest REE miner able to supply its thriving consumer products manufacturing needs.

b. The China Factor

China's monopoly in the REE industry was, and remains today, so strong that many companies across the globe observe it is the country steering the path the REE industry should take.

In 2010, China breached WTO rules on international trade by introducing a quota policy on REE trade. This is when other players, particularly from the western world, began looking for alternative sources of REE supply, but even with this drive from the likes of USA and EU, we still see companies facing difficulties to enter the industry and become viable competitors. This is because China has already perfected the art of REE value chain development.

In Africa, China is already actively acquiring concessions for REE exploration



and mining. It may be possible to consider partnering with Chinese investors but Chinese entrepreneurs are known for making deals that best serve their national interests, and they can provide sovereign funding at government level with assets like REE deposits being mortgaged to the loan. Such deals have the effect of allowing Chinese businesses to effectively run 100% owned operations in Africa with little benefit to local communities, or host country or region. With some western companies also investing in African reserves, the possibility of a scramble for REE assets in Africa between China and the western world businesses cannot be ruled out.

c. Scarcity of Funds and lack of funding structures

Traditionally Africa has been dogged by downstream value chain investment because of the lack of funds for such projects. Value addition requires huge investment, which, in the current economic environment is a major obstacle for many African states. Only South Africa has an economy that can support investment in value addition but what they can afford is dwarfed by countries like China and the West.

If Africa wants to actively pursue industrialization and economic development, the answer lies in value addition. Governments enact measures that support entrepreneurship, especially in value addition, while at the same time promoting regional cooperation, to create the best environment for investment in projects. Mining and mineral processing are capital intensive ventures which require a sound financial base to consider venturing into this business sector.

While China typically uses sovereign funds to expand its business interests beyond its borders, the West world can boast of well-defined funding structures, which enables its entrepreneurs to invest in territories around the globe. The following is a typical funding structure for mining projects by western businesses:

Mineral Exploration – Due to the high risks involved, funds for exploration are mainly raised through private equity and public listing on stock markets.

Private equity includes investment or placements from wealthy individuals, hedge funds, pension funds, insurance companies, and charities whereas public listing involves selling shares on stock markets like the LSE. These funders are the organizations with appetite for higher risk (and reward), unlike investment banks that typically require risk-management following preliminary assessments such as a feasibility study and preparation of Information Memorandum (IM).

Mine Development and Mining – Once an information memorandum is prepared banks are more prepared to finance the development of the mine using various funding options like project finance provided the content of the IM meets all the requirements of the financial institution. To achieve these funding methods, there is a series of procedural investigations to ascertain profitability, which calls for highly skilled personnel and consultants to establish the information required.

Processing and Marketing: If project viability is almost guaranteed, banks are in a position to finance the project at an agreed loan to value ratio, which effectively unlock the value in the commodity from mining through processing to production of final product.

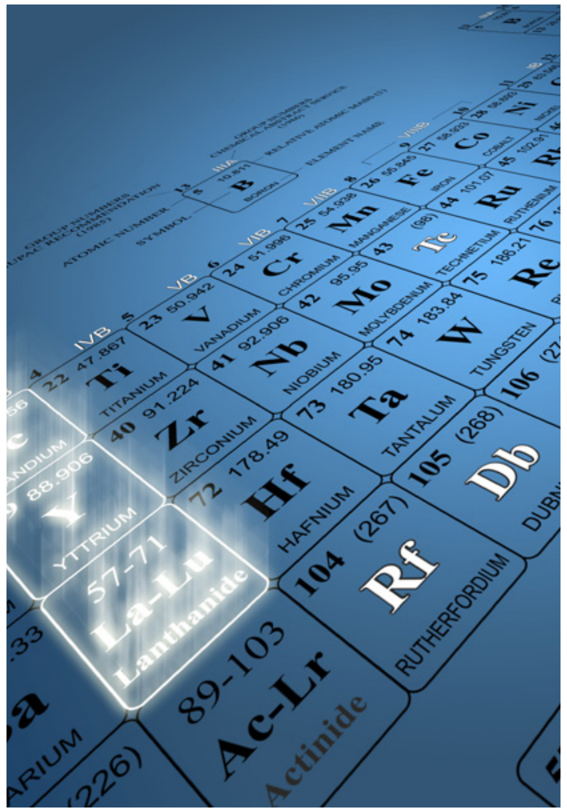
Africa lacks this systematic lending structure developed by the western world. African states will need to create such robust funding structures if a sustainable home-grown business is to be developed. With the prevailing situation remaining, Africa may not be able to fully compete in the industry, and will continue to see China and the western world investing in the upstream side of the value chain only, and see potential earnings from a full value chain investment being exported together with the concentrate.

d. Business Acumen

Existing players have an advantage over the new entrants. This barrier is significant as there can be no substitute for experience. The fact that African entrepreneurs have not been actively participating in mining businesses implies that their knowledge of the business is limited, and they have no experience of delivering an efficient and sustainable mining operation. This poses a high risk to would-be financiers of the project. For that reason, African owned businesses may find raising capital difficult, whether private equity or debt finance. Several mining projects owned by citizens of Africa have failed to take off either due to lack of funds or lack of business impetus. As a result, many African entrepreneurs in the mining sector end up selling their assets to the more experienced businesses with the financial muscle to develop the mineral resource.

e. Legal Barriers

Governments can inadvertently create legal hindrances to new entrants by granting few exclusive rights, to a few companies. These are protectionist strategies adopted by governments especially where they are state-owned or are strategic to the economic development of the country. Governments should be able to create an environment promoting local as opposed to foreign investment as a means to create country-rooted economic development. Foreign companies simply shut down operations when the mineral resource runs dry but local companies attempt to innovate and diversify, thus contributing to economic development beyond the life of the mining project.



f. Marketing Barriers

In any business, marketing is important as it helps to sell the product and therefore generate revenue streams for a sustainable operation. In most mining operations, marketing is minimal because most mining products are commoditized and sold on metal exchanges at predetermined prices either as a hedge, forward, future or spot. This is however not the case with REE. Due to the dominance of China in this market, prices tend to be determined by the Chinese market or individual negotiations between miners and off-takers, making it difficult for new entrants to efficiently negotiate a price that reflects the true value of the commodity. Big players are already fully established, thus can drive price negotiations and influence the outcome. They also have the financial muscle to develop comprehensive marketing suites in regions they choose to invest in. These circumstances represent a barrier to entry for new players.

7.4 Summary

Aside from the China factor, barriers include inadequate skills especially for the downstream processing of REEs, scarce exploration capital to conduct mineral exploration sufficinetly detailed to attract large scale investors and inadequate logistics to support downstream value addition.

08

Conclusions, Recommendations and Action Plan

8.1 Conclusions

i. Africa's significant REE Resources: REE, is critical for the future technological advancement of African countries, especially as the world moves towards a zero CO2 emission future. The mineral resource is available in Africa and has been shown to be abundant in at least eleven countries with strong prospects of commercial viability. It compares well with other deposits globally, with superior grades and higher HREE/LREE ratio as observed from SKK and Gakara projects, implying higher value on a one to one tonnage comparison. The fact that South Africa and Tanzania are on the list of top ten countries by mineral reserves is a signal of Africa's potential position, with several other projects elsewhere in Africa showing prospective results. Based on the distribution of projects on the continent it can be concluded that most REE development projects are concentrated in southern and eastern Africa where conducive geological conditions to support deposition of the metals to economic levels have been known to exist for a long time.

ii. Africa's Share of global REE Resources: The current world REE reserve stands at 120 Million tonnes, with China contributing 44 Million tonnes to that figure, equivalent to 37% of the world's total reserves. A total of 4 million MT (inferred) resource has been estimated for Africa. A major advantage of Africa's REE resources is the quality of the deposits, which is generally high compared to other parts of the world. This has attracted stock market-financed exploration by junior companies as the deposits demonstrate quality REE resource availability outside China. Two of the deposits, Lofdal in Namibia and SKK in South Africa have high CREO content, an upside potential for REE value chain development in Africa as its deposits can meet the right quality of REE on the market.

iii. China Risk – Opportunity for Africa: China has maintained a monopoly in the production of REE for more than 25 years but with REE becoming critical in key industry sectors of economies, the world's major REE consumers are increasingly concerned about a single source of supply for their industry needs; in particular is China's quota policy on REE trade, which impacts the supply system causing price volatility and uncertainties. Many countries are gradually shifting their focus to other global regions for supply and Africa is seen as the new frontier for the world's REE supply. Africa can take advantage of this new development to ensure the existence of good policies on REE investment that create a win-win situation between the investors and the continent's economic developmental needs.

iv. Project Prospects in Africa: Several companies are already investing on the continent defining mineral resources in several African states. Rainbow Rare Earth is already producing REE concentrate in Burundi and Steenkampskraal Holdings is also on the verge of restarting production at its Steenkampskraal mine in the Cape province of South Africa. These are positive developments for Africa as it seeks to cement its foothold in the REE industry. The respective governments should provide support to the development of these mineral development projects while at the same time creating the environment for local participation at investor and executive management levels.

v. Value Chain Development: Companies investing in Africa come with different business models - Rainbow is mining the Gakara deposit as far as mineral concentrate production, SHHK is developing the Steenkampskraal until production of REE salts, and Frontier and Ionic are planning to develop the whole value chain to produce separate oxides. This is encouraging for Africa as the potential for benefitting from employment creation, revenues, taxes etc is there with the development of these minerals. Africa should next focus on attracting investment in the production of consumer goods from the refined REE commodity.

8.2 Recommendations

i. Promote linkages with other economic sectors for REE development: There is a symbiotic interplay between different sectors of the economy and REE development can only be achieved if that relationship is promoted. African countries need to implement systems that support economic development starting from the level of governance. Major state institutional functions that promote value chain development include good governance, national economic (and monetary) policies, infrastructure and logistics development, transparency, education, and communication. The pillars of value chain development will suffer if any of these state functions are weak.

ii. Resource the African Minerals Development Centre (AMDC) to coordinate strategy development for critical minerals: For maximum benefit from its natural resources, Africa should resource the AMDC to coordinate the development and implementation of strategies for metals and mining including critical minerals such as REE, Lithium, and Cobalt. With this approach, Africa would be able to develop a robust system of investment which promotes local participation, complete value chain development, the engagement of local service providers and contractors, and eventual investment in consumer goods manufacturing, while at the same time implementing policies that allow easy access to regional and continental geological data, transparent and competitive bidding for licenses and marketing the potential of the continent to both domestic and external investors.

iii. Develop investment promotion strategy for value chain development: The natural progression of developing the industry sector is to create an environment promoting open and transparent investment. African countries endowed with mineral resources should put in place policies that promote value chain development, like providing incentives to companies that consider developing the value chain beyond beneficiation (concentrate production). Incentives could be in the form of tax holidays during payback period, or the waiver of import duties. in the local or regional arena, incentives could be in the form of funds that can be accessed by locals to invest in such projects and therefore create a competitive edge for local investment.

iv. Improve the macroeconomic environment: African states need to review their monetary and fiscal policies to avoid currency volatility. High currency volatility is an unwelcome risk for investment in any sovereign state. Mining investment is long-term, and investors are attracted to jurisdictions with stable currency to be able to make predictable life of mine (LOM) plans. In addition, high volatility results in companies and high net worth investors banking their money in stable countries outside Africa, which in turn negatively affects the lending capacity of a country. This (in addition to lack of transparency) is a major problem in some African countries which makes it difficult for the development of home-grown investments – financial institutions are left with no lending capacity when money is externalized. Governments should arrest causes of money externalization.

v. Representation on global REE industry association: It is important that African countries keep track of events in any industrial developments (probably best done by the AMDC) to resonate, at par, with developments happening in other parts of the globe. An example is the lack of any African representation on the Rare Earth Industry Association (REIA) that was launched in Brussels in June 2019 to promote investment and transparency in the REE business. Africa's high-tech industry is understandably still in its infancy but now is the time to develop an engagement strategy for the anticipated industrial development requirements in the near future. It is therefore extremely important for Africa to cooperate in the development of the REEs to contribute to a common strategy and in order to have an influential voice in the global REE landscape. This is the only way Africa can address the inherent imbalances in the global rare earths value added markets worldwide.

vi. Development of strong financial institutions: Africa needs to develop strong institutions, in particular the banking sector which is currently mainly focused on retail (personal and commercial) and trade finance. There is a need to develop investment banking as a driver of economic development. Countries should develop institutions like pension funds, hedge funds, insurance, and wealth management funds capable of pooling resources for big investments like a mining operation. Frontier is probably failing to develop its huge Zandkopsdrift deposit into production because of lack of financial institutes to finance the project.

vii. Promote joint ventures with Western and European companies to develop REE deposits: In addition to developing home-grown financial institutions with the capability to finance huge projects, African states should take advantage of the US and European Union's shift towards Africa for their REE requirements in their bid to balance the China risk. African states should encourage their local entrepreneurs to engage in joint ventures with experienced companies. Having indigenous players participate in the supply chain is the best way of transferring knowledge and skills to local content as China and Japan did to develop their levels of industrialization. A strategy should be put in place that promotes local businesses in the economy, and that includes the REE value chain. This could be a starting point for local participation which should transition to full consolidation with time as they develop their business acumen.

viii. Build a risk resilient environment for supply chains: The continent witnessed disruptions to supply chains, operations, and skills availability from COVID-19 mainly because these resources are outsourced from other continents. It is therefore important to develop a strategy aimed at localizing these supply chains using the enormous resources in Africa. The strategy must be holistic – accounting for all the risk factors and providing mitigatory measures. The strategy should also address existing constraints in the mineral value chain, at country and regional levels, to facilitate end-to-end industries to produce consumable goods needed as input for other sectors. For example, developing local skills and a 'home grown' supply chain with most of the raw material requirements for mining operations sourced locally can significantly mitigate the effects of shocks like pandemics whenever they occur.

8.3 Action plan to implement recommendations

In this implementation plan, the key provisions are grouped into clusters. These have also been scheduled into short-term (1-3 years), medium-term (4-8 years) and long-term (9-12 years) time periods, depending on the critical nature of their implementation to the realization of the objectives. The mode of implementation of this plan by various institutions are to be determined by each Member State or RECs as detailed in Table 10.

	REE VALUE CHAIN ANALYSIS: ACTION PLAN FOR IMPLEMENTATION OF RECOMMENDATIONS				DURATION [YEARS]			
NO	STRATEGIC OBJECTIVE	ACTIVITIES	OUTPUT	OUTCOME	SHORT TERM	MEDIUM TERM	LONG TERM	RESPONSIBILITY
					1 to 3	4 to 8	9 to 12	
1	Develop Investment Promotion Strategy for Value Chain Development	Develop REE specific policy and legal framework	REE policy, legal and regulatory framework	Investors attracted into the REE sector				NG, RECs, Industry, ASM Associations
		Develop incentive schemes to attract investors	REE constrained Incentive schemes					
		Create a website of existing geological information on REE to allow remote access by potential investors	Digitize REE information including infographics	Investment attracted into exploration of REEs				
		Develop models for ASM participation in REE mining where possible	ASM framework	ASMs licensed to operate				
		Package information on existing REE deposits in the eleven countries already identified for potential investment for end to end operations	Information packaged and available online	Investors attracted for negotiations				NG, RECs, Industry
2	Promote Linkages with other Economic Sectors for REE Development	Develop an integrated industrial strategy with specific roles for REE products e.g, magnets, electronic components etc.	Integrated industrial strategy with specific roles for REE	Manufacturing hubs established for REE products				NG, Industry etc
		Establish specific linkages with other economic sectors to enhance value chain development	Linkages with trade, research institutions etc. established	REE sector linked with sectors of the economy				
		Develop supply chains to increase local content in the sector	Supply chains established	Local content in REE sector increased				
3	Resource the African Minerals Development Centre (AMDC) to Coordinate Development of Strategy for Critical Minerals	Strengthen the AMDC to facilitate development of an African strategy for critical minerals	African strategy for critical minerals (including REE)	Investment attracted to develop end to end manufacturing of REE products				AUC and Partners
		Facilitate development of REE strategy at the REC level (SADC, EAC, ECOWAS etc.). This will increase the probability for smaller REE deposits becoming profitable.	1. REC strategies; 2. Development of regional REE Projects	Regional REE end to end projects				AUC, RECs, NG, Industry
4	Represent Africa on Global REE Industry Association	Develop Framework for Africa's Representation on Global Industry Associations. The framework will allow national representatives of REE endowed countries as well as continental representation for an Africa common position on issues.	Framework for Africa's representation developed	Africa has a voice and common position in global REE Agenda				NG, AUC, AMDC and Partners including AfDB
5	Develop Strong Financial Institutions	Facilitate establishment of an African Stock Exchange (ASE)	1. Modalities developed;	2. ASE established				Africa Union, AfDB etc.
		Facilitate sourcing funds from non-traditional sources such as pension funds, hedge funds, insurance for huge investments	Strengthened financial sector for investment	Number of investment institutions attracted to provide financing for mineral projects				Africa Union, AfDB, NG etc.
6	Promote Joint Ventures with Foreign Companies to Develop REE Deposits	Facilitate JVs between local players in the REE supply chain and Foreign experienced companies for transfer of knowledge and skills transfer.	JVs deals between locals and foreign REE value chain companies	Resources and reserves defined				NG, RECs, Industry
		Incentivize advanced projects on the continent to develop end-to-end operations of the REE value chain	REE end-to-end companies attracted	Magnets and electronic products factories established				NG, RECs, Industry
		Facilitate educational and industrial tours for industry professionals	Industrial tours facilitated for hands on experience	Technical skills acquired for end to end manufacturing of REE products				NG, Industry
	ABBREVIATION	AfDB: African Development Bank; AMDC: Africa Minerals Development Centre; AU: Africa Union; NG: National Government and REC: Regional Economic Community						

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