South Africa's mineral resource availability as a potential driver for transitioning to a circular economy

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Abstract

The aim of this paper was to establish if mineral resource scarcity is a driver for South Africa to transition to a circular economy. The project objectives were achieved by investigating economically viable, and critical or strategic minerals remaining in South Africa, as well as resource scarcity, as a driver for South Africa to transition to a circular economy. The study found that some minerals in South Africa, such as iron ore, lead, manganese, gold, and cobalt have less than 50 years of economically viable mining remaining. At least 18 minerals can be classified indicatively as critical or strategic: aggregates, bauxite, chromite, cobalt, copper, gold, graphite, iron, limestone, lithium, manganese, nickel, phosphorous, platinum group metals, rare earth elements, silver, titanium, and vanadium. The classification was based on the minerals' economic importance, supply risk, and potential use in the development and manufacturing of emerging technologies.

The findings suggest that the scarcity of mineral resources is a critical driver for the country to transition to a circular economy. Other identified drivers include socio-economic factors, climate change commitments, and business objectives. All minerals are non-renewable resources and at risk of depletion, therefore sustainable extraction and use are critical. Priority should be directed at investigating circular economy opportunities and substitutes for commodities at risk of being depleted within the next 50 years. There is an opportunity for South Africa to transition from a minerals export-based model to one that promotes local mineral beneficiation and manufacturing of end products.

Keywords

circular economy, critical minerals, critical raw materials, resource scarcity, strategic minerals

Introduction

Circular economy (CE) is defined by the Ellen MacArthur Foundation as a systematic approach to economic development designed to benefit businesses, society, and the environment (EMF, 2017). In the South African mining sector, the popular economic model is a 'take-make-dispose' model where resources are extracted, used for a short period, and then discarded back into the environment. This generates large amounts of waste materials, water, and energy (Nahman, et al., 2021). Contrary to the 'take-make-dispose' economic model, a circular economy entails 'keeping materials and products in circulation for as long as possible through practices such as reuse and repurposing of products, sharing of underused assets, repairing, recycling and remanufacturing' (Schroder, 2020).

Mining can simply be defined as the extraction of mineral deposits from the surface or subsurface of the earth. The methods that are used to extract mineral deposits can be generally classified into underground and surface mining (Hartman, 1987). Surface mining methods are used to extract near-surface mineral deposits, while underground mining methods are used to extract deep orebodies that cannot be economically mined using surface mining methods (Hartman, 1987). Mining was historically left outside the CE loop; however, recent studies show that CE may present many opportunities to the mining sector through the sustainable use of natural resources (Lebre, et al., 2017) (Figure 1).

This paper explores CE from a resource perspective and in the context of the South African mining sector.

Objectives

The objective of the study detailed in this paper was to determine whether South Africa's (SA) resource availability is a potential driver to transition to a CE in the South African mining sector. The approach taken to achieve these objectives was by answering the following research questions:

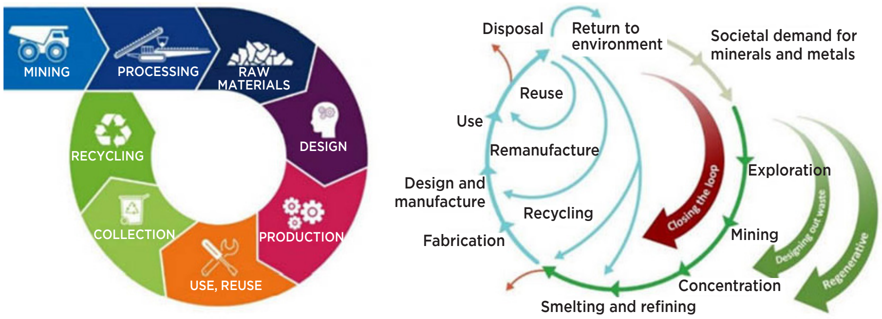

Figure 1—Integrating the main life cycle stages for minerals and metals into circular economy (ICCM, 2016; IET, 2018)

- ➤ How many years of economically viable minerals and metals does SA have?
- ➤ What are potentially SA's critical/strategic minerals?
- ➤ Is resource scarcity a driver for SA to transition to a more CE?

Literature review

South African mineral landscape

SA is rich in natural resources, particularly minerals. The mining and metals sector (MMS) comprises nine subsectors: cement, lime, aggregates, and sand (CLAS); coal mining; diamond mining; diamond processing; gold mining; jewellery manufacturing; platinum group metals (PGM); services incidental to mining; and other mining, which includes the mining of iron ore, chrome, manganese, copper, and phosphates (MQA, 2021).

The MMS has contributed greatly to the South African economy and provides both direct, and indirect employment. The MMS employs more than 450 000 workers, whereby the majority are employed in the PGM (163 538), gold (93 682), and coal (91 459) subsectors (Statista, 2021).

Some of the commodities that the country hosts include gold, PGM, coal, diamond, copper, chrome, iron, lead, manganese, nickel, titanium, vanadium, zinc, andalusite, fluorspar, phosphate, vermiculite, asbestos, and uranium. In terms of its mining contribution to the country's GDP, SA ranks as fifth in the world (Wits Mining Institute, 2020). Of the total global reserves, SA hosts 88% PGM, 80% manganese, 75% chromite, and 13% gold reserves (Wits Mining Institute, 2020).

The South African mining industry is unique and gradually evolving in that complex ore bodies are being mined at greater depths. Consequently, challenges, such as increasing operating costs, aging infrastructure, and severe health and safety concerns become apparent (Mitchell, 2016). Additionally, there is an increased demand for access to reliable energy, better quality of resources exploited, and interventions for transitioning to carbon neutrality (OreFlow, 2020).

Defining critical raw materials

Critical raw materials (CRM), as defined by the European Union (EU), are raw materials that are economically and strategically important to the European economy and have a supply that is subjected to high risk (Ferro and Bonollo, 2019), whereas strategic minerals are minerals/metals that are also essential to the economy, modern technology and industry, have a limited supply, and are subject to disruption (Bharat, n.d.). In SA, the concept of CRM is relatively new, and the term 'strategic minerals' is generally accepted as CRM, as both are economically important and their supply is associated with high risk, therefore these terms may be used interchangeably in SA. These minerals could be critical to a variety of sectors for commercial and governmental applications, for example, green technology, telecommunication, space explorations, aerial imaging, aviation, medical devices, micro-electronics, transportation, defense, and other high-tech products (Critical Raw Materials Alliance, 2020). Additionally, the lack of viable substitutes for these essential minerals, because of their unique and reliable properties, further adds to their critical nature.

Critical minerals and emerging technologies

The existing EU formula for determining CRM could not be adopted in the South African context due to its complexity and the lack of data in SA. Therefore, the technology landscape was assessed to identify emerging technologies that will drive the demand for specific minerals and metals rendering them critical.

Globally, countries are steadily transitioning to renewable energy (RE) to sustain energy requirements and meet increasing energy demands whilst also trying to reduce their carbon footprint. This has given rise to the use of electric vehicles (EV), batteries, wind turbines, solar, and hydropower, which all contribute greatly to the reduction of greenhouse gas emissions (GHG) (Buschke, et al., 2021). Furthermore, the digital transformation of the twenty-first century has led to the development of cutting-edge technologies that are critically dependent on several minerals, thus any resource-rich country needs to have an informed understanding of the correlation between RE and digital technologies respective to the required minerals/metals.

The rapid adoption of EV coupled with low carbon future targets has placed minerals/metals like rare earth elements (REE), PGM, lithium, and cobalt, among others, in high demand. The automotive industry is the leading driver of platinum demand, and the use of platinum as a substitute for palladium has amplified its demand (Creamer, 2021). Notably, some of these potential CRM are not actively mined in SA. One example of a mineral not currently mined in SA is bauxite for aluminium production, which has properties critical to CE in that it can be infinitely recycled and thus has been dubbed as 'a metal of the future' (Kapur, 2020).

Clean energy technologies, the military, and consumer electronics have increasingly been associated with REE, and growth in these sectors is directly proportional to the demand for REE (Massachusetts Institute of Technology, 2016). Although SA hosts only about 0.7% of the world's REE reserves and no active mining has occurred, reserves are reported to be of very high grade (Steenkampskraal, 2022).

Current trends in technology development and adoption indicate a transition toward sustainability in sectors such as mining being inevitable (Anglo American, 2019). For the mining industry in SA to be in the optimal position to exploit opportunities that will arise from this transition and technology evolution, it is essential to understand the resources available, their applicability, technology trend adoption, and minerals properties such as recyclability, available substitutes, and quantity.

Methodology

The methodology entailed collating secondary data through a literature review and gathering primary data through the use of qualitative research methods comprising stakeholder engagements and survey questionnaires. Stakeholder engagements were conducted through two workshops and interviews between January and February 2022. The stakeholder groups for the first workshop included geologists, mining engineers, mineral economists, and mineral resource management practitioners. The stakeholder groups for the second workshop included environmental management practitioners and professionals involved in issues related to sustainability and environmental, social and governance (ESG), and materials stewardship.

The information solicited enabled the project team to answer the research questions for this study.

Determining the remaining number of years of economically viable minerals in SA

A reserve is that part of an in situ demonstrated resource that can be economically extracted or produced at the time of estimation (SAMCODES, 2016). The years to depletion of minerals in SA was calculated using secondary mineral reserve and production data as shown in Equation 1 (Parry, 2021).

$$Years\ to\ depletion = \frac{Total\ remaining\ tonnage\ of\ mineral\ reserve}{Total\ annual\ production\ tonnage\ of\ run\ of\ mine\ ore} \quad [1]$$

Mineral reserve and production data were obtained from different sources including the Minerals Council South Africa (MCSA), Statista, United States Geological Society (USGS), and the World Nuclear Association. The units of the data for reserves and production were standardised to million tonnes (Mt). The mineral reserve for each commodity was reported in terms of metal content and the annual production for each commodity was reported in terms of the tonnage of the saleable product.

Determining SA's critical raw materials/strategic minerals

At the time this study was undertaken, there was no well-defined methodology for determining CRM in SA. Different countries have used various methods over time to determine the criticality of raw materials, which vary due to differences in mineral resource strategies based on a country's mineral endowment and mineral resource access. Martin et al. (2022) introduced a method in Spain that uses three quantifying indicators: overall supply, environmental impacts of sourcing material, and environmental justice threats at the sourcing location. In Germany, the Economic Product Importance method was introduced to evaluate the relevance and significance of a specific raw material for a particular product system (Lütkehaus, et al., 2022).

The EU methodology was selected as a reference for determining CRM in SA for several reasons. Firstly, it is an established methodology that has been used and refined over time, making it a reliable reference point. Secondly, the criticality of raw materials in the EU methodology is linked to demand driven by technological advancements, which aligns with the current global context of technological advancement and innovation. Thirdly, unlike other countries, SA has a substantial mineral endowment that renders certain variables in the methodologies from other countries less significant. Therefore, the EU methodology's adaptability to different contexts makes it a suitable reference for SA's criticality evaluation. However, it should be noted that data availability, accessibility, and accuracy are critical in any methodology. Since there may be challenges with the availability and accessibility of data relating to mineral resources in SA, a 'hybrid' methodology that adapts elements of the EU approach was selected.

The EU uses two key parameters for determining the criticality of materials, which are: economic importance (EI) and supply risk (SR), as shown in Equation 2 and Equation 3.

$$EI = \sum_s (A_s \times Q_s) \times SI_{EI} \quad [2]$$

Where:

EI = Economic importance
As = The share of an end use of a raw material in an NACE Rev 2 (2-digit level) sector
Q_s = The sector's VA at the NACE Rev (2-digit level)
SI_{EI} = The substitution index of a raw material related to economic importance
S = denotes sector

$$SR = HHI_{WGI}\ x\ (1 - EoL_{RIR})\ x\ SI \quad [3]$$

Where:

SR = Supply risk
HHI = Herfindahl Hirschman index
WGI = scaled World Governance index
IR = Import reliance
EoL_{RIR} = End-of-life recycling input rate
SI = Substitution index (in supply risk)

It was found that the EU methodology could not be used as-is in the South African context due to the complexity of the variables it uses in its formulae and the lack of appropriate local data. To address this, CRM in SA were determined by linking minerals to emerging technologies, which links to the 'economic importance' parameter in the EU methodology. This was done by taking cognisance of the fact that the world has been in a steady transition of adopting many disruptive technologies, such as clean-energy and Fourth Industrial Revolution (4IR) technologies. The intention of linking minerals with technologies was to understand which minerals will be in demand in the future in terms of parameters such as offering opportunities for socio-economic growth, gross domestic product (GDP) contribution, employment, and reducing the environmental impact of mining.

As of November 2024, a critical minerals strategy, including a critical minerals list for SA, is in the process of being developed by the South African government. The list provided in this paper was defined only for the purpose of achieving the objectives of this study and was primarily focused on energy transition minerals, which have an export significance in the context of SA. Once the strategy is finalised, the critical minerals list for SA will be officially adopted.

Determining if resource scarcity is a driver for South Africa to transition to a more circular economy

This research question was addressed based on the results of the preceding research questions and through the collection of qualitative data from engagements with stakeholders.

Results and discussion

South African economically viable minerals and years to depletion

The results showing the remaining years to depletion of mineral commodities are reported in ranges and summarised in Table 1.

The detailed reserve and production data used in the calculations for each mineral commodity is shown in Table 2.

The limitation of the equation used was that the years to depletion determined in this study were based on current knowledge of parameters such as current reserves, current production rates, and demand and supply and are therefore indicative figures. However, it is acknowledged that various technical and economic factors could affect the reserves and production values, such as the dynamic nature of reserves, geological factors, demand, and commodity prices.

The results indicate that three (3) minerals (iron ore, lead, and manganese) could potentially be depleted in less than twenty (20) years of mining, two (2) minerals (gold and cobalt) in twenty to fifty (20 -50 years), one (1) mineral (zinc) in fifty to one-hundred (50 - 100) years, four (4) minerals (coal, copper, PGM, and vanadium) in 100 - 500 years, and nine (9) minerals (chromium, fluorspar, nickel, phosphate, titanium, uranium, vermiculite, zirconium, and diamonds) could potentially be depleted after five-hundred (500) years. Even though SA hosts large reserves of graphite and REE, there is currently no production – despite positive growth in demand for these minerals globally. Both have an expected compound annual growth rate (CAGR) greater than 4%.

As per the project scope, the years to depletion calculations considered in situ underground reserves only. However, recommendations for future work include investigating reserves in tailings storage facilities and/or waste dumps, as mining of tailings and waste dumps may prove to be economically viable. The results indicating that some minerals have less than 50 years of economically viable mining remaining raises concerns regarding mineral scarcity and the impacts thereof.

Table 1

Summary of remaining years to depletion of mineral commodities

Range of years to depletion	Mineral commodities
< 20	Iron ore, lead, manganese
20 – 50	Gold, cobalt
50 – 100	Zinc
100 – 500	Coal, copper, PGM, vanadium
> 500	Chromium, fluorspar, nickel, phosphate, titanium, uranium, vermiculite, zirconium, diamonds

South African critical raw materials and strategic minerals

From the selected approach, eighteen (18) minerals were identified as potentially critical or strategic in SA, based on their applicability and importance to emerging technologies and in their respective sectors. A summary of the minerals corresponding to emerging technologies is shown in Table 3.

Table 2

Input data and years to depletion for mineral commodities

Commodity	*Total remaining reserve (Mt) in 2020	*Annual production (Mt) in 2020	Range of calculated years to depletion
Chromium	200 000	14.513	> 500
Coal	53 156	247.11	100 - 500
Cobalt	0.04	0.000897	20 - 50
Copper	11	0.029068	100 - 500
Diamonds	130 000 000	8.471642	> 500
Fluorspar (contained CaF)	41	0.00032	> 500
Gold (metal)	0.0032	0.000096	20 - 50
Graphite	790 000	Currently no production	
Iron ore	690	55.635308	< 20
Lead (metal)	0.3	0,028048	< 20
Manganese (metal)	260	16,059758	< 20
Nickel	3 700	0.034908	> 500
PGM	63	0.226	100 - 500
Phosphate rock (contained concentrates)	1400	0.0021	> 500
REE	200 000	Currently no production	
Titanium minerals	35	0.0011	> 500
Uranium (metal, up to $US 80/kg U)	0.2791	0.00025	> 500
Vanadium (metal)	3.5	0.0082	100 - 500
Vermiculite	14	0.00014	> 500
Zinc (metal)	14	0.160816	50 - 100
Zirconium minerals (metals)	6.5	0.00032	> 500

*Source: IBM, (2020); MCSA, (2021); Statista, (2020); USGS, (2021); World Nuclear Association, (2021)

Table 3

Summary of emerging technologies with corresponding minerals required for technology development

Emerging technology	Corresponding minerals required to develop the technology
Hydrogen fuel cells	Platinum, rare-earth elements (REE), PGM, cobalt, vanadium, manganese
3D printing	Titanium, magnesium, REE, lithium
Solar photovoltaic cells	REE, copper, aluminium, indium, gallium, selenium, silver, tellurium
Robotics	Cobalt, chrome, lithium, vanadium, PGM
E-mobility (electric vehicles)	Manganese, nickel, copper, PGM, vanadium, cobalt, natural graphite, lithium
Drones and UAV	Manganese, chromium, nickel, copper, tellurium
Cloud and remote computing	Copper, REE, indium, tungsten
Energy storage	Copper, cobalt, nickel, lithium, REE

The identified critical or strategic minerals in SA are shown in Table 4 and Figure 2.

From the literature review and the hybrid methodology selected, findings regarding the CRM identified are aligned to findings from later research that was conducted by VBKOM (VBKOM, 2023), apart from coal that was not listed in the authors' results. The reason for the exclusion of coal was that coal is not linked to an emerging technology, even though it is economically important. Furthermore, coal is not part of the green energy transition, it is however, recognised as a key mineral since SA is still heavily reliant on coal for power generation.

The stakeholders that were engaged were of similar views in terms of CRM that were identified, with the addition of minerals from the construction and agriculture sectors. The stakeholders concurred with the general observation that local beneficiation of these resources is lacking, such that growth is limited in local industries like manufacturing, and it must thus be improved, as quoted, '*We would like to mine minerals and use them within SA rather than export them*'.

Key comments and suggestions from stakeholders regarding CRM are summarised below:

➤ An understanding of the quantity of minerals and commodities will improve understanding of the requirements

Table 4

South Africa's strategic minerals

Critical/strategic minerals in SA	Justification for criticality status
Aggregates	Essential in the construction sector
Bauxite	Essential in aluminium production, metallurgy, chemical industry, and use as a catalyst. SA does not have bauxite reserves.
Chromite	Essential in robotics, UAV; steel production in SA accounts for about 70% of the world's chrome reserves.
Cobalt (Co)	Essential in energy storage technology and EV economy, however, SA was ranked 10th in world production in 2020.
Copper (Cu)	Essential in solar photovoltaic (PV) cell production, electric mobility (e-mobility) industry, drones and unmanned aerial vehicles (UAV), remote computing, and energy storage.
Gold (Au)	Gold is important to the SA economy for its vital contribution to the GDP, employment, and for attracting foreign capital. Scarcity of gold resources and difficulty in mining are being experienced. SA was ranked 7th in production with 100 tonnes in 2021.
Graphite	Essential in the e-mobility industry, however, SA has no graphite operations.
Iron (Fe)	Essential in steel making; steel is highly recyclable, reusable, and can be used for renewable energy infrastructure and transportation networks.
Limestone	Essential in steel manufacturing, mining, paper production, water treatment and purification, and plastic production.
Lithium (Li)	Essential in green energy technologies, electric vehicles (EV), and electronics. SA has no lithium extraction or processing, however, can play a role in the refining and processing stage (Stage 3) as a key supply chain stage. SA does not have significant lithium reserves.
Manganese (Mn)	Essential in the steel industry, hydrogen fuel cells, e-mobility, and UAV. SA possesses the largest manganese reserves at 5.5 million tons and is the leading producer. However, production has decreased in 2020.
Nickel (Ni)	Essential in e-mobility, drones and UAV, and energy storage.
PGM (individual elements listed below):	Often used as catalysts. SA holds 88% of the world's PGM reserves.
Iridium (Ir)	Essential in use as a hardening agent for platinum, also used in spin electronic devices.0
Osmium (Os)	Essential in producing very hard alloys for fountain tips, instrument pivots, needles, and electrical contacts. Also used in the chemical industry as a catalyst.
Palladium (Pd)	Essential in catalytic convertors. Can also be used in jewelry, medicine, and recently started being used in fuel cells to power cars.

Table 4 (continued)

Critical/strategic minerals in SA	Justification for criticality status
Platinum (Pt)	Essential in the motor industry with use as a catalytic converter, also used in laboratory equipment, electrical contact, and electrodes.
Rhodium (Rh)	Essential in use as a catalytic converter for cars, jewelry chemical, and electrical trades.
Ruthenium (Ru)	Essential in the chemical industry for coating anodes of electrochemical cells for chlorine production, can also be used in solar cells.
Phosphorous	Essential in the agriculture sector for fertilising purposes.
REE (individual elements listed below):	Essential in clean energy, defense technologies, high-tech devices, and LED lighting. SA only holds about 0.7% of the world's REE reserves.
Cerium (Ce)	Used in electronics like lights, TVs, and ovens.
Dysprosium (Dy)	Used in wind turbines, EV, and nuclear reactors when mixed within alloys.
Erbium (Er)	Used in lasers and fibre optics cables.
Europium (Eu)	Used in light bulbs, nuclear reactors, and lasers.
Gadolinium (Gd)	Used in magnets, nuclear reactors, and magnetic resonance.
Holmium (Ho)	Used in magnets and nuclear reactors.
Lanthanum (La)	Mixed within alloys that are used in batteries and hydrogen vehicles.
Lutetium (Lu)	Used as a catalyst in refineries.
Neodymium (Nd)	Used in magnets and lasers.
Praseodymium (Pr)	Used in aircraft engines, fiber optic cables, and magnets.
Promethium (Pm)	Used in pacemakers and guided missiles.
Samarium (Sm)	Used in microwave devices and and other electronic devices such as stereos and headphones devices.
Scandium (Sc)	Used for fuel cells and alloys used in jet planes.
Terbium (Tb)	Used in light bulbs, memory devices, and X-rays.
Thulium (Tm)	Used in lasers.
Ytterbium (Yb)	Used in displays, x-ray machines, and fibre-optic cables.
Yttrium (Y)	Used in radars and as an additive within allows used in high-tech devices.
Silver	Essential in alloys, batteries, light emitting diode (LED) chips, PV energy, electronics, and jewellery.
Titanium	Essential in rechargeable batteries, electronics, medicine industry, and EV.
Vanadium	Essential in hydrogen fuel cells, robotics, and e-mobility.

*Source: Arcelormittal (2019); Anglo American (2015); Anglo American (2019); Basov (2022); Britannica (2021); BYju's (2022); DMR (2014); Geology.com (2022); Geology News and Information (2014); Goodenough et al. (2021); Minerals Education Coalition (2016); Nickel Institute (2022); Passels (n.d.); Pistili (2021); Royal Society of Chemistry (2022); US Energy Information Administration (2022); Yuksel (2021)

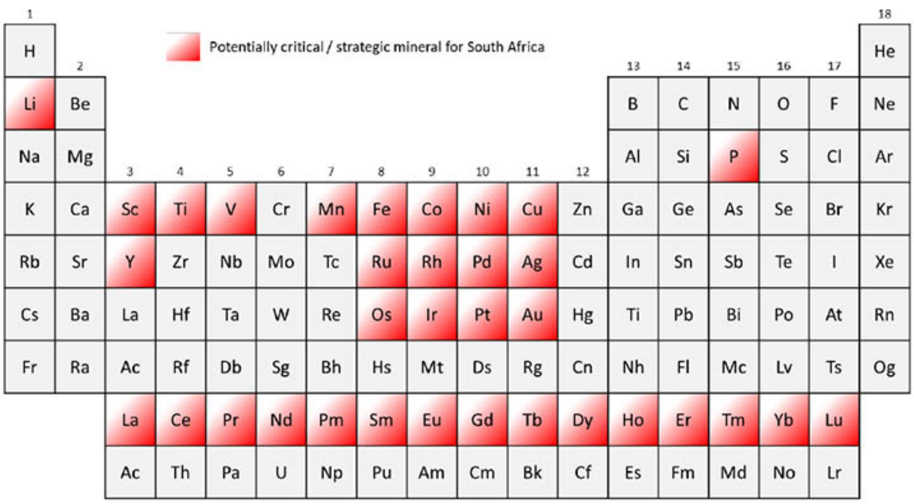

Figure 2—Summary of SA's potentially CRMs or strategic minerals

for the transition towards CE and can also put SA in an optimal position to manufacture and maintain technologies locally.

- Localisation and local beneficiation should be further assessed.
- Beneficiation to leverage mineral demand through the manufacturing industry to reduce the heavy reliance on exports is important.
- The importance of drawing the link between manufacturing and metals since the demand for certain minerals will be driven by the technologies regardless of whether certain minerals are produced locally or exported.
- Although SA remains in support of greater local beneficiation, one participant stated, "*It is likely we will remain a net exporter of a lot of our new resources*".
- Investigate alternative or replacement materials for those minerals that are at high risk of depletion.
- REE and PGM must be looked at individually to determine the criticality and application of each element to contribute to further economic growth. Although the relevance of REE to SA has been recognised, the challenges associated with the mining of REE include supply chain, processing, environmental and geopolitical issues (Jellicoe, 2019). Investigate alternative economies that might arise with these emerging technologies, which may, in turn, unlock new employment opportunities.

As the results suggest, some minerals that were classified as critical in SA have less than 50 years of economically viable mining remaining (cobalt, gold, iron ore, lead, and manganese). It is therefore crucial that they be extracted and utilised in a sustainable manner to ensure that current and future minerals and metals demands are met. Although adopting circularity within the mineral value chain may be a potential solution for sustainable resource use, these minerals are mostly exported, suggesting that SA may have little control over their downstream circularity. This in turn shows the importance of local beneficiation and local manufacturing in SA so that the country may benefit from its own resources. Additionally, the idea of resource leasing as opposed to resource sales to trading partners may be further explored as a potential means to encourage responsible and sustainable resource use.

Resource availability (or scarcity) as a driver for a circular economy in South Africa

Coupled with several factors, resource scarcity is indeed the driver for CE in SA, although it is not the primary driver. The finite nature of resources, coupled with the excessive use that results from the global adoption of the 'take-make-waste' economy, ultimately result in constant resource shortage risk and inevitable depletion (Govindan, et al., 2015). With this reality in sight, CE may offer alternative solutions that will ensure economic and environmental sustainability, and the responsible consumption of natural resources. A CE may offer an alternative option that will optimise materials by aiming to keep them in use for as long as possible (PwC, 2019).

Certain international companies have already started using recycled materials for their electronic applications (e.g., Apple uses aluminum, copper, tin, and tungsten). Research conducted by the Organisation for Economic Co-operation and Development (OECD) showed drivers for the transition to a more CE, and in addition to resource scarcity, they include economic development, climate change, global agendas, private sector initiatives, technological developments, and others (OECD iLibrary, 2022). Moreover, certain minerals have less than 50 years of economic viability, with some of these classified as strategic or critical in SA. The remaining years of economic viability of minerals, coupled with the finite nature of natural resources, which will eventually be depleted further, emphasise the availability and the supply constraints.

Key comments from stakeholder engagements pertaining to resource scarcity being a potential driver for the transition to a more circular economy are summarised in the following:

- Consider presenting CE from a growth and job creation standpoint in SA.
- Although SA is a resource-rich country, the answer to the driver for the transition has been challenging to specify because CE emerged from a resource scarcity context, however, the focus has now shifted.
- In instances where there are thousands of years of resources remaining, resource scarcity cannot be the driver for the transition. It then becomes essential to quantify jobs and new businesses that could be unlocked through CE.
- Some opportunities that could be derived from CE from mining operations could benefit mining communities socially, economically, and environmentally, however, understanding communities' skills is key in exploiting these opportunities.
- Drivers for CE transition are not limited to one factor but several, like the need for optimised processes, materials, and waste valorisation, limited supply of critical resources, climate change, global initiatives, economic growth, employment opportunities, population growth, and energy demands.

Conclusion and recommendations

This paper details the methodology and findings of a study undertaken to determine if resource scarcity is a potential driver for SA to transition to a CE. Three key research questions were addressed in this paper, relating to remaining economically viable minerals in SA, critical or strategic minerals in SA, and resource scarcity as a driver for transitioning to a CE.

The findings revealed that there are less than 50 years of economically viable mining of certain minerals in the country, suggesting the risk of mineral depletion and its consequences. Adopting circularity may mitigate this risk, however, these minerals are mainly exported and thereby limits the country to implement interventions to control the use of these minerals to benefit the economy and the people.

Eighteen minerals were identified as potentially critical or strategic in SA due to their economic importance and supply risk. The critical minerals in SA include aggregate, bauxite, chromite, cobalt, copper, gold, graphite, iron, limestone, lithium, manganese, nickel, PGM, phosphorous, REE, silver, titanium, and vanadium.

Based on the findings, it was concluded that resource scarcity may in fact be a driver for SA to transition to a CE. Other drivers include the need for job creation, socio-economic factors, climate change commitments, and business objectives. All mineral commodities are scarce and should be used sparingly, sustainably, and responsibly for the benefit of present and future generations. Urgent priority should be aimed at those commodities that may potentially be depleted within the next 50 years of extraction, i.e., cobalt, gold, iron ore, lead, and manganese, by identifying and investing in CE opportunities for these commodities. These minerals, however, are mostly exported, suggesting that SA may have little control over their downstream circularity. The importance of local beneficiation and manufacturing was emphasised in the study, especially as the demand for critical or strategic minerals increases. It is recommended that local beneficiation and local manufacturing should be prioritised so that SA may have control over its resources and potentially realise its long-term benefits.

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