



IMPACT ANALYSIS OF CRITICAL RAW MATERIALS: Mining and Use for the Green Hydrogen Economy in South Africa

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JOHANNESBURG



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CHAPTER 1: INTRODUCTION

- Critical Raw Materials (CRMs) like PGMs and REEs are key to the Just Energy Transition and green hydrogen technology.
- South Africa holds a **strategic role** due to rich CRM reserves and abundant renewables.
- Green hydrogen relies on **PGMs in fuel cells and electrolysers**—sustainable mining is crucial.
- **Opportunities:** PGM beneficiation, exports, job creation. **Risks:** Declining IC engine demand, mining impacts.
- CRM mining **affects ecosystems, water, land, and communities**—women face unique vulnerabilities.
- Emphasises **circular economy:** CRM recycling, reduced extraction, resilient supply chains.
- **Spatial analysis maps** CRM mining impacts and guides sustainable green hydrogen value chains.

CRITICAL MINERALS FOR THE GREEN TRANSITION IN SOUTH AFRICA

Critical Raw Material	Technology	Use
Platinum Group Metals (Platinum and Iridium)	<ul style="list-style-type: none"> • PEM electrolyzers & Hydrogen fuel cells 	<ul style="list-style-type: none"> • Enable hydrogen production and are essential for hydrogen-powered energy systems
Rare Earth Elements (Neodymium, Dysprosium, yttrium and lanthanum)	<ul style="list-style-type: none"> • Magnets for turbines & fuel cell vehicles, • Solid oxide fuel cells (SOFCs) 	<ul style="list-style-type: none"> • Support renewable energy technology and efficient power generation

CRITICAL MINERALS FOR THE GREEN TRANSITION IN SOUTH AFRICA

Critical Raw Material	Technology	Use
Manganese	<ul style="list-style-type: none"> Lithium manganese oxide (LMO) batteries 	<ul style="list-style-type: none"> Enhances stability and reduces reliance on cobalt
Vanadium	<ul style="list-style-type: none"> Vanadium redox flow batteries (VRFBs) 	<ul style="list-style-type: none"> Large-scale renewable energy storage & hydrogen production
Lithium	<ul style="list-style-type: none"> Lithium-ion batteries 	<ul style="list-style-type: none"> Renewable energy storage & green hydrogen production
Graphite	<ul style="list-style-type: none"> Bipolar plates of fuel cells 	<ul style="list-style-type: none"> Enables electricity flow in fuel cells & strengthens hydrogen storage systems.

CRITICAL MINERALS FOR THE GREEN TRANSITION IN SOUTH AFRICA

Critical Raw Material	Technology	Use
Nickel	<ul style="list-style-type: none">Alkaline Electrolysers	<ul style="list-style-type: none">Effective electrode material
Cobalt	<ul style="list-style-type: none">Lithium-ion batteries	<ul style="list-style-type: none">Storing renewable energy used in hydrogen production

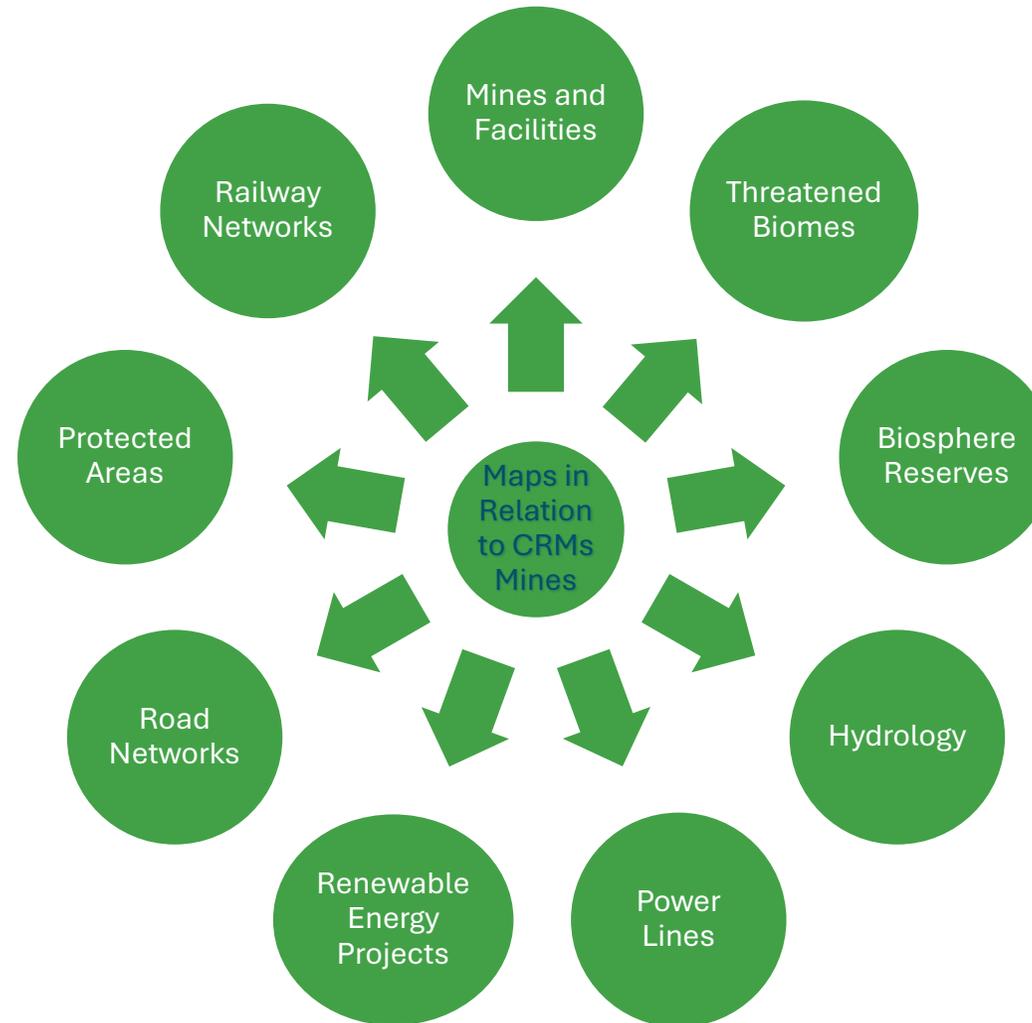
CHAPTER 2: RESEARCH OBJECTIVES

1. Analyze the impacts of CRM extraction for green hydrogen production.
2. Map the spatial distribution of CRM mining and its environmental and community effects.
3. Assess the sustainability of mining operations in the green hydrogen value chain.
4. Focus on key CRMs (PGMs, REEs, nickel, cobalt, manganese, vanadium, lithium, graphite) vital for green hydrogen technologies.
5. Evaluate environmental and socio-economic impacts on air, water, land, biodiversity, and communities.
6. Model future CRM demand with different growth scenarios.
7. Explore technologies to improve mining efficiency and reduce environmental impact.
8. Validate findings through workshops and stakeholder feedback.

CHAPTER 3: SCOPE AND LIMITATIONS

- Based on desktop-level data and publicly available information.
- Predictions are theoretical due to data processing and research limitations.
- High-level analysis, with potential influences from market dynamics and socio-economic forces.
- Limited stakeholder engagement; mining industry responses were less robust than expected.
- Future workshops will address engagement gaps, especially in the mining sector.
- Assumes current mining methods remain unchanged

CHAPTER 5: Maps of CRMs Production in South Africa



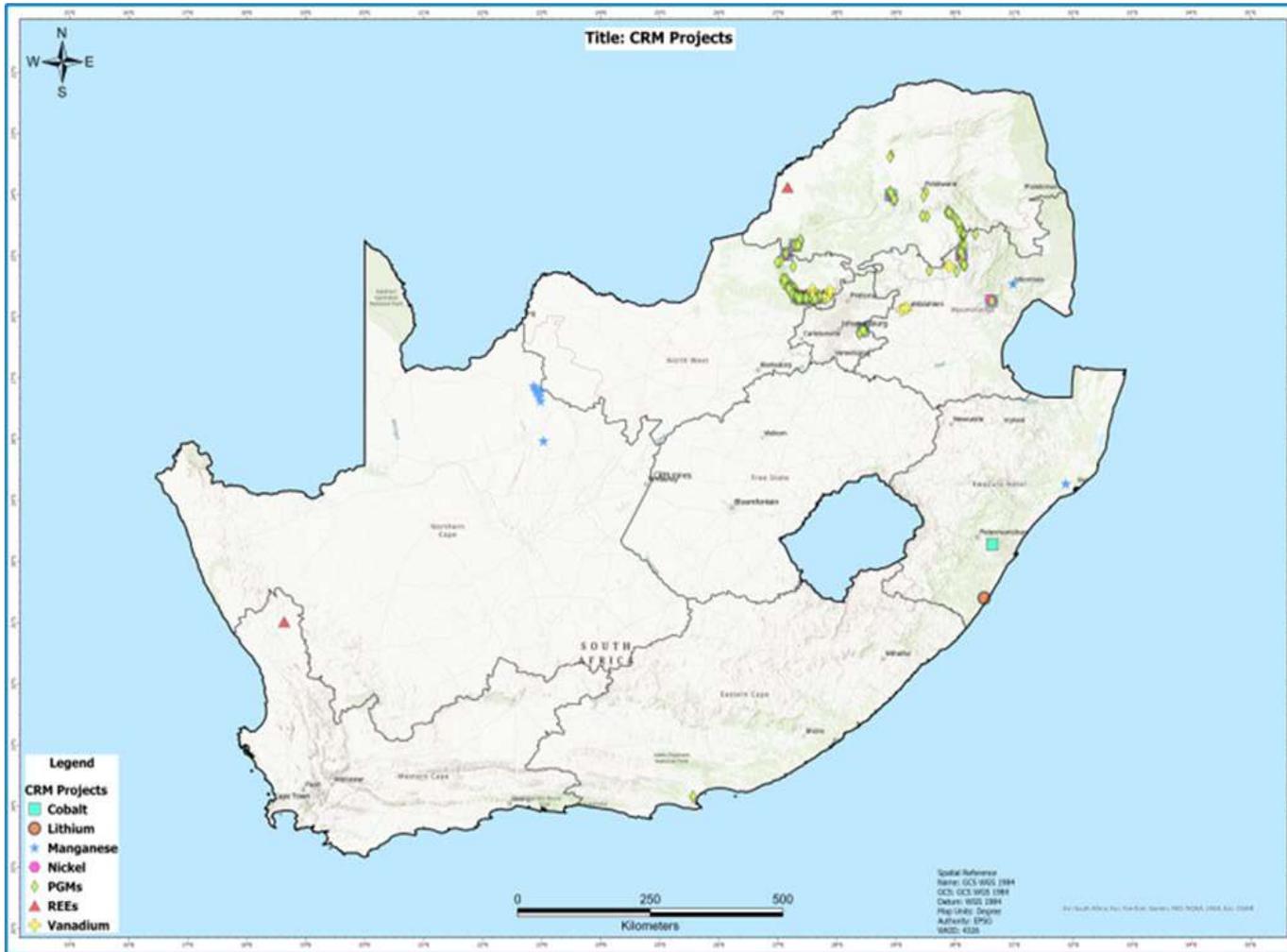


Figure: Critical Raw Materials- Mines and Facilities

North-West Province:

- Dominated by Platinum Group Metals (PGM) mines in the Bushveld Igneous Complex, known for its extensive layered intrusions that yield platinum, palladium, rhodium, and vanadium.

Northern Cape:

- Dominated by manganese projects, with minor lithium, nickel, and REE projects. REEs are also found in the Western Cape.

Cobalt:

- Sparse, located in Kwa-Zulu Natal, Mpumalanga, Limpopo, and Northwest provinces.

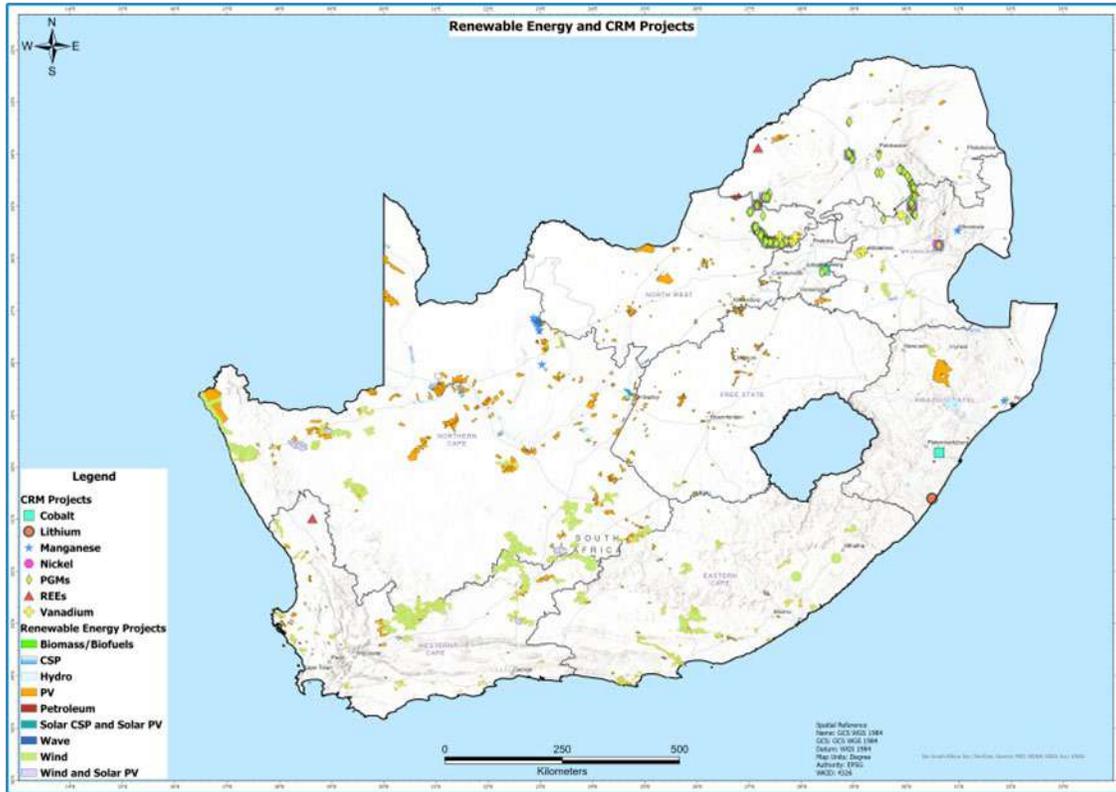
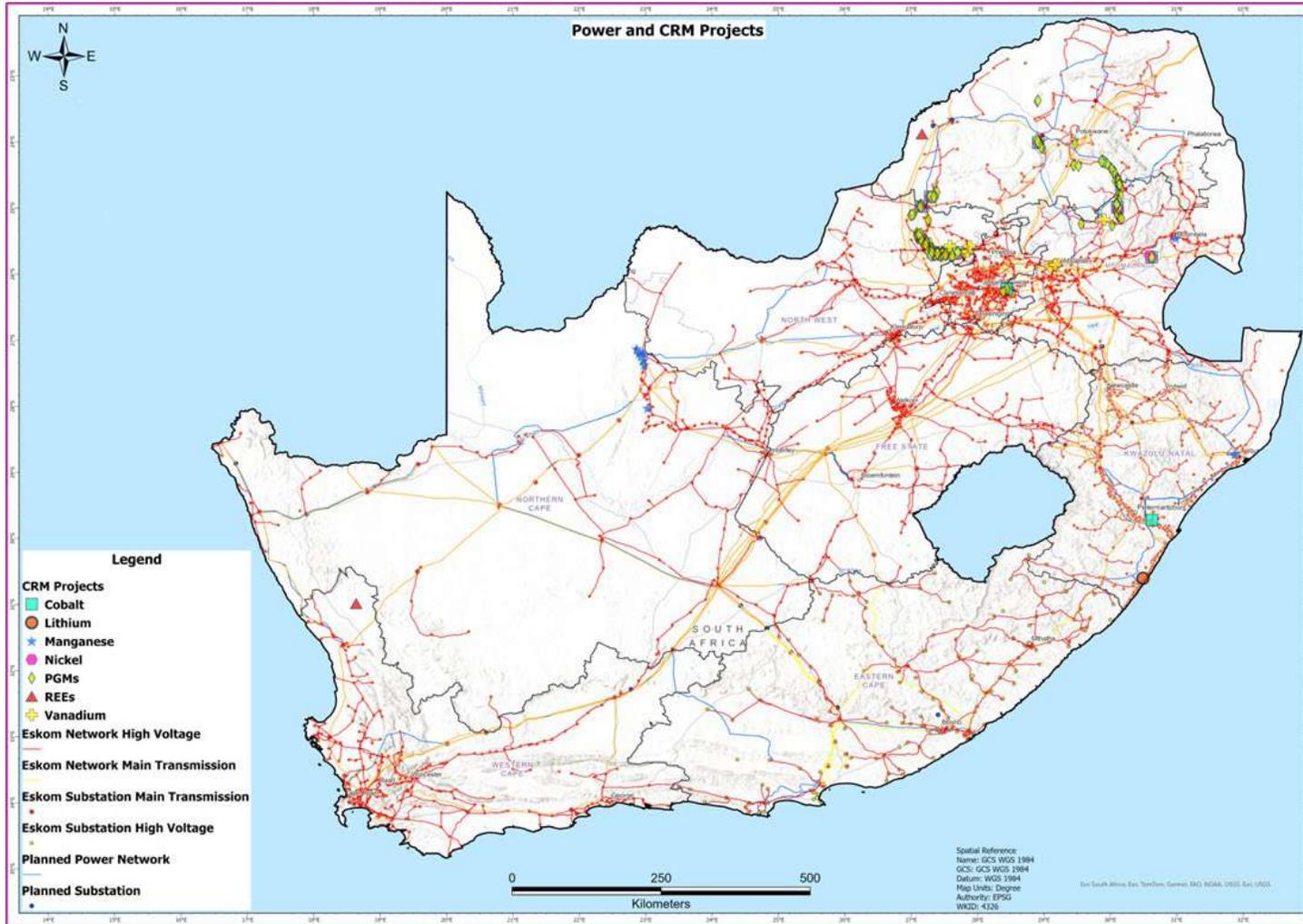


Figure: Critical Raw Materials- Renewable Energy Projects



Figure: Critical Raw Materials- Hydrology

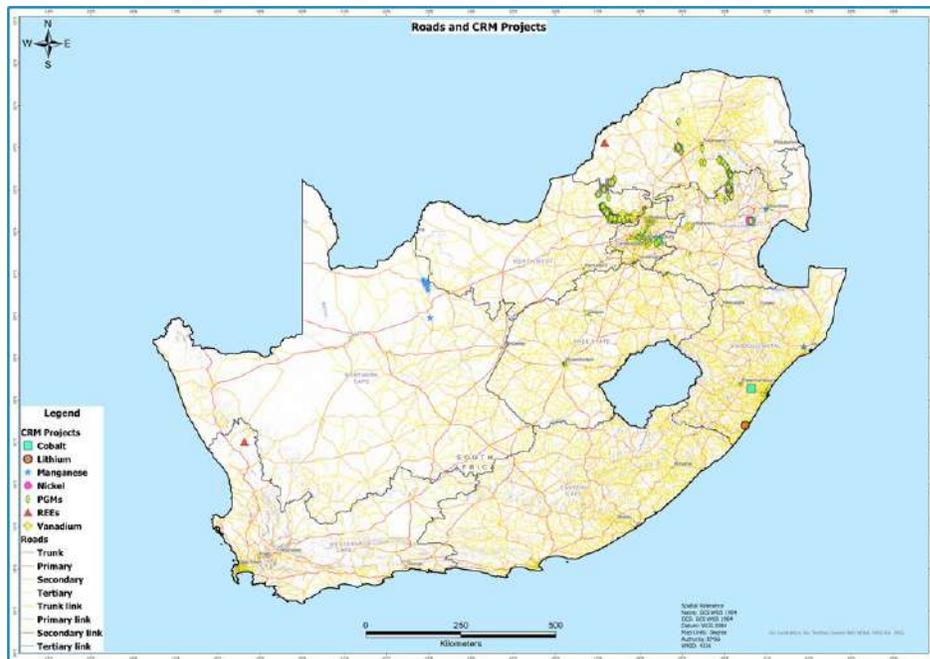


- Power Lines are distributed according to the densely populated areas
- There are significant amount of lines that feed into the mining regions

Figure: Critical Raw Materials- Power Lines

Key Road Corridors:

- **Maputo Corridor:** Connects northeastern provinces to Mozambique's port, featuring projects like the N4 highway.
- **South Africa Corridor:** Links Durban and Cape Town ports to Gauteng, with major highways N1, N2, and N3.



Key Rail Corridors:

- **North South Railway Corridor:** Links Durban to Zimbabwe, Botswana, DRC, and Zambia.
- **Trans-Oranje Railway:** Undergoing upgrades to connect Namibia's ports to Johannesburg via the Northern Cape.

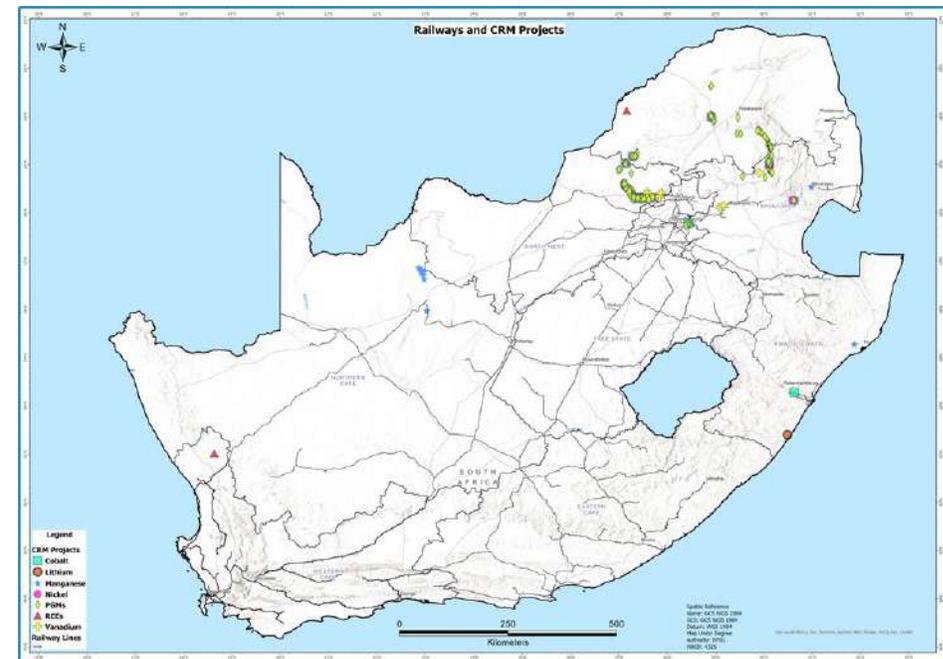


Figure: Critical Raw Materials- Road Network

Figure: Critical Raw Materials- Railway Network

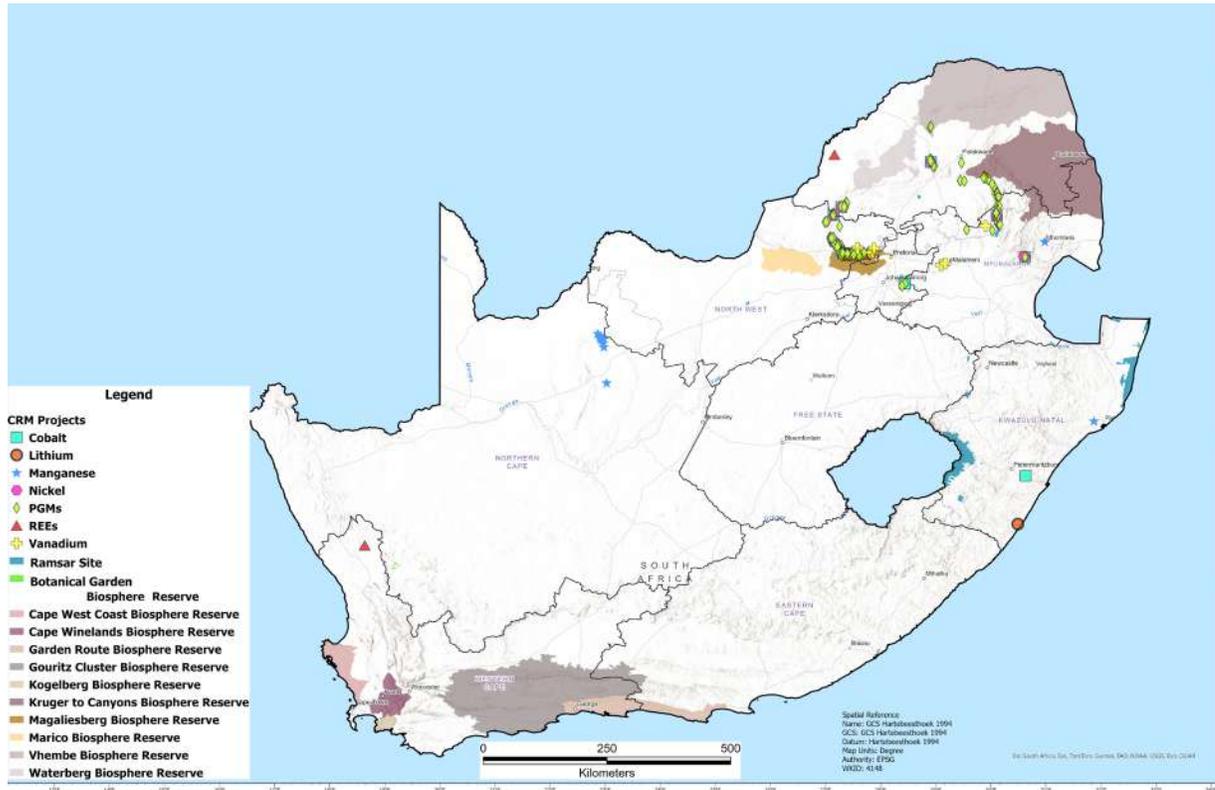


Figure: Critical Raw Materials- Conservation Areas

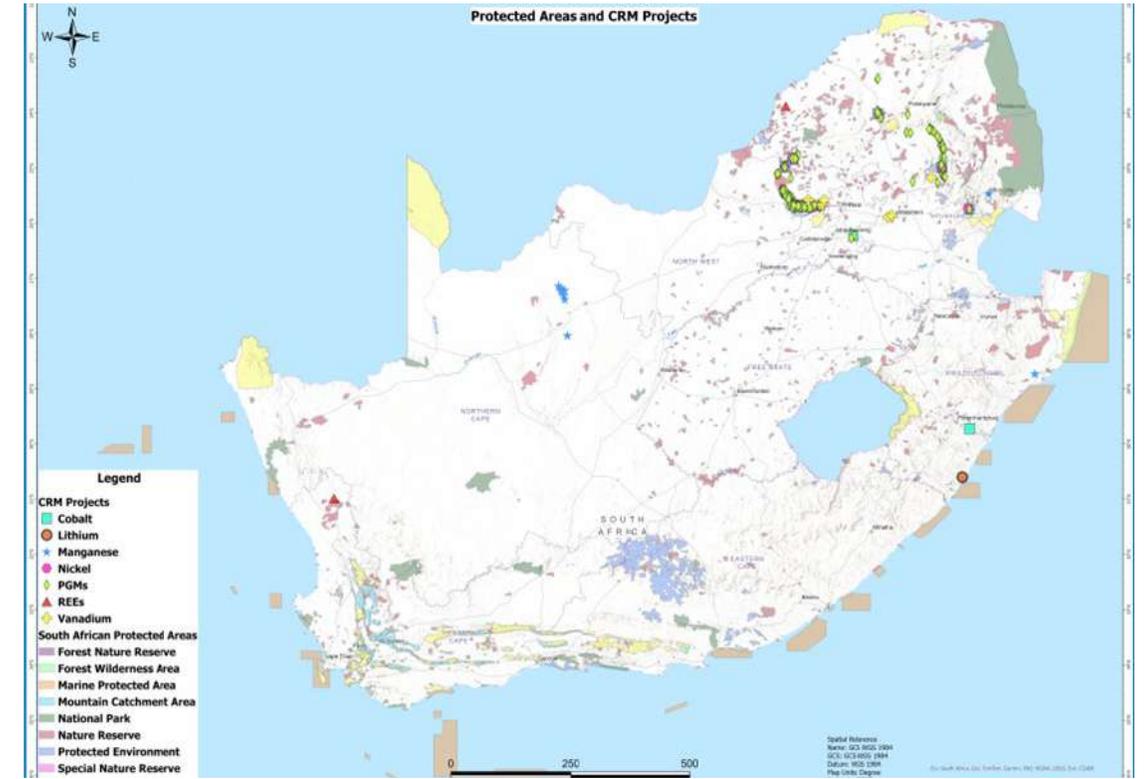


Figure: Critical Raw Materials- Protected Areas

Environmental Impacts



Biome & Biodiversity

Mining overlaps with endangered biomes (Grassland & Savannah), Grasslands, covering 30% of SA, are critically endangered with only 3% protected.



Pollution

Use of hazardous chemicals (cyanide, sulfuric acid) leads to soil, water, and air contamination, heavy metals disrupt ecosystems



Hydrology

Mining impacts key river systems (Limpopo, Olifants, Crocodile, Vaal) via water contamination, depletion, and acid mine drainage



Infrastructure

Mining regions face grid, rail, and road infrastructure challenges; RE projects are distant from mining zones, limiting integration



Air Quality

Mining emits particulate matter, SO₂, NO_x—linked to respiratory diseases and environmental harm

CHAPTER 6: CRMs Scenario Analysis and Risk Assessment

The International Energy Agency (IEA) had identified sixteen Critical Raw Materials (CRMs) required for the Green Hydrogen Transition (GH₂).

To achieve global NZE targets by 2050, a total of 37 CRM's are required for clean energy transitions

A techno-economic model was developed. These distinguished CRMs were quantified under mineral demand for the three scenarios, namely

- Stated Policy,
- Announced Pledges
- Net Zero Emissions by 2050.

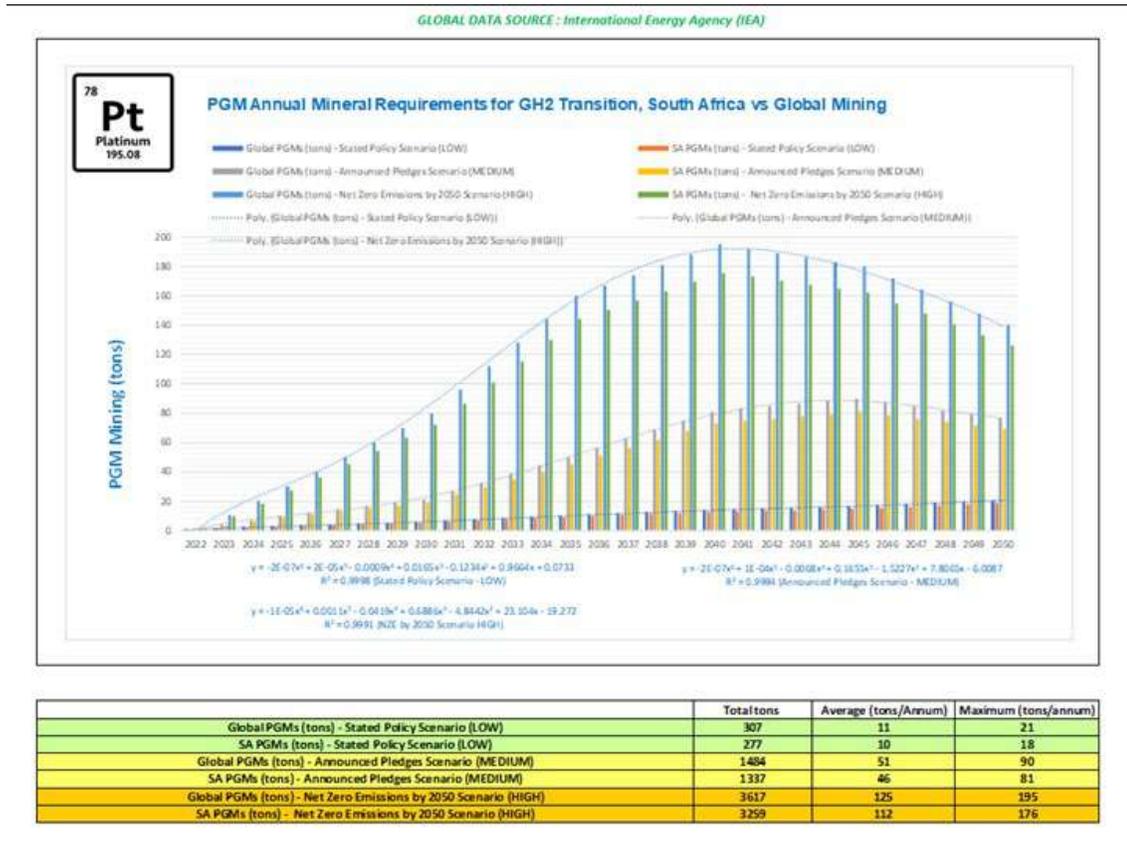
CRMs	South African Resources
Platinum	90%
Nickel	100%
Cobalt	100%
Zirconium	25%
Manganese	80%
Vanadium	10%
Lithium	2%
Graphite	0,30%
Iridium	81%
Copper	2%
Titanium	100%
Dysprosium	17%
Yttrium	1%
Praseodymium	8%
Neodymium	13%
Terbium	8%

South African Critical Raw Materials
expected contribution towards the Green
Hydrogen Transition

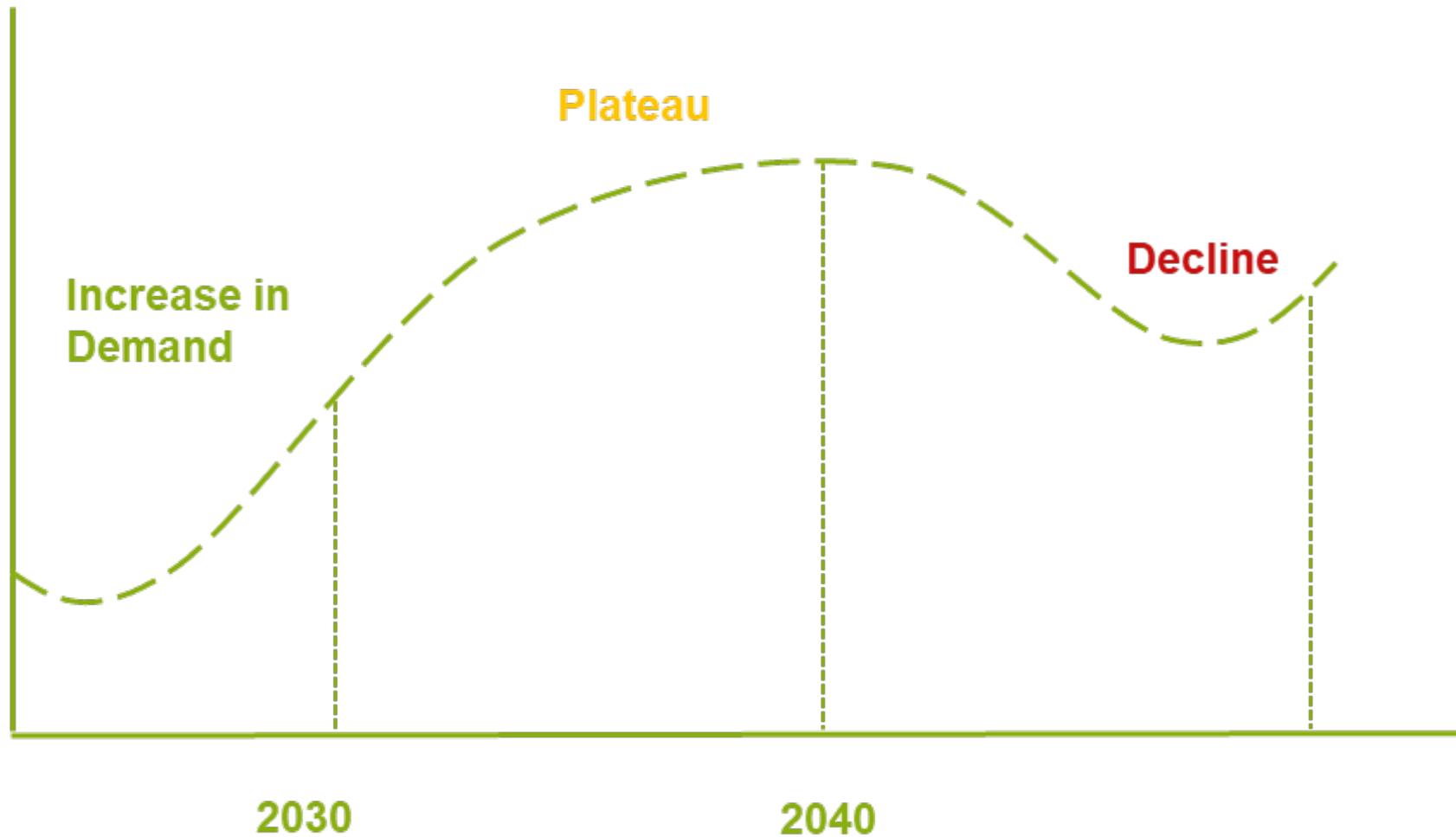
The following variables were considered during the analysis

- South African resources were quantified for all sixteen CRM's.
- Annual mining production data 2018 to 2023
- Annual Mineral Pricing 2018 - 2023
- Energy Demand
- Water Demand
- GHG Emissions
- Rock to Mineral (RMR) Ratios

Example of Demand Scenario Graphs for CRMs



Overall General Trend



Three Key Trends in Scenarios

1) Ramp-Up Phase (2022 to ~2035)

- There's a sharp increase in CRM demand over the next 10–15 years.
- This is because of new mining and processing activities being launched in response to climate policies and global efforts to reduce emissions.

2) Decline or Plateau (After ~2035 to 2050)

- After the ramp-up, CRM demand starts to level off or decrease.
- Why? Better technologies for processing ores and waste reduce how much raw material is needed.
- Some CRMs cannot be easily replaced in future tech, so their demand plateaus, not drops.
- Rise in Recycling: Recycling becomes more common, reducing the need for new mining.
- This helps explain the overall decline in demand for mined CRMs after the ramp-up period.

3) Small Final Increase (Before 2050)

- A small bump in CRM demand is expected just before 2050.
- This is likely due to a final push in mining and production to meet last-minute targets for net-zero emissions.

CRMs Demand and its Impact on the Environment

- Greenhouse Gas (GHG) emissions
- Water usage
- Energy demand
- Land disruption (e.g., habitat destruction, soil degradation)

Trends

- **Short-term:** Rising CRM demand increases environmental pressure — more energy, emissions, water, and land use.
- **Long-term:** Recycling and planning can reduce impacts, but sustainable management is essential for a just green hydrogen transition.

CHAPTER 7: SOCIO-ECONOMIC IMPACTS OF CRMS MINING

Socio-Economic Benefits

Infrastructure & Economic Growth:

- Drives development of infrastructure and manufacturing.
- Creates employment, especially in mining regions.

Economic Inclusion & Empowerment:

- Mining Charter mandates **30% B-BBEE** shareholding for new rights.
- Empowers historically disadvantaged individuals.

Local Content & Supplier Development:

- Enhances community participation and job creation.
- Supports local businesses through preferential procurement policies.

Social Investment & Community Development:

- Companies invest in education, health, safety, and infrastructure.
- Partner with NGOs and social programmes.



Socio-economic Drawbacks

Health & Safety Risks:

- Workplace injuries, NIHL, TB, HIV/AIDS, and silicosis.
- Health issues impact workers, families, and communities.

Environmental Health Impacts:

- Water pollution (high iron & manganese).
- Poor air quality affects livelihoods and well-being.

Social & Economic Vulnerabilities:

- Frequent stoppages disrupt livelihoods.
- Environmental degradation leads to long-term challenges.

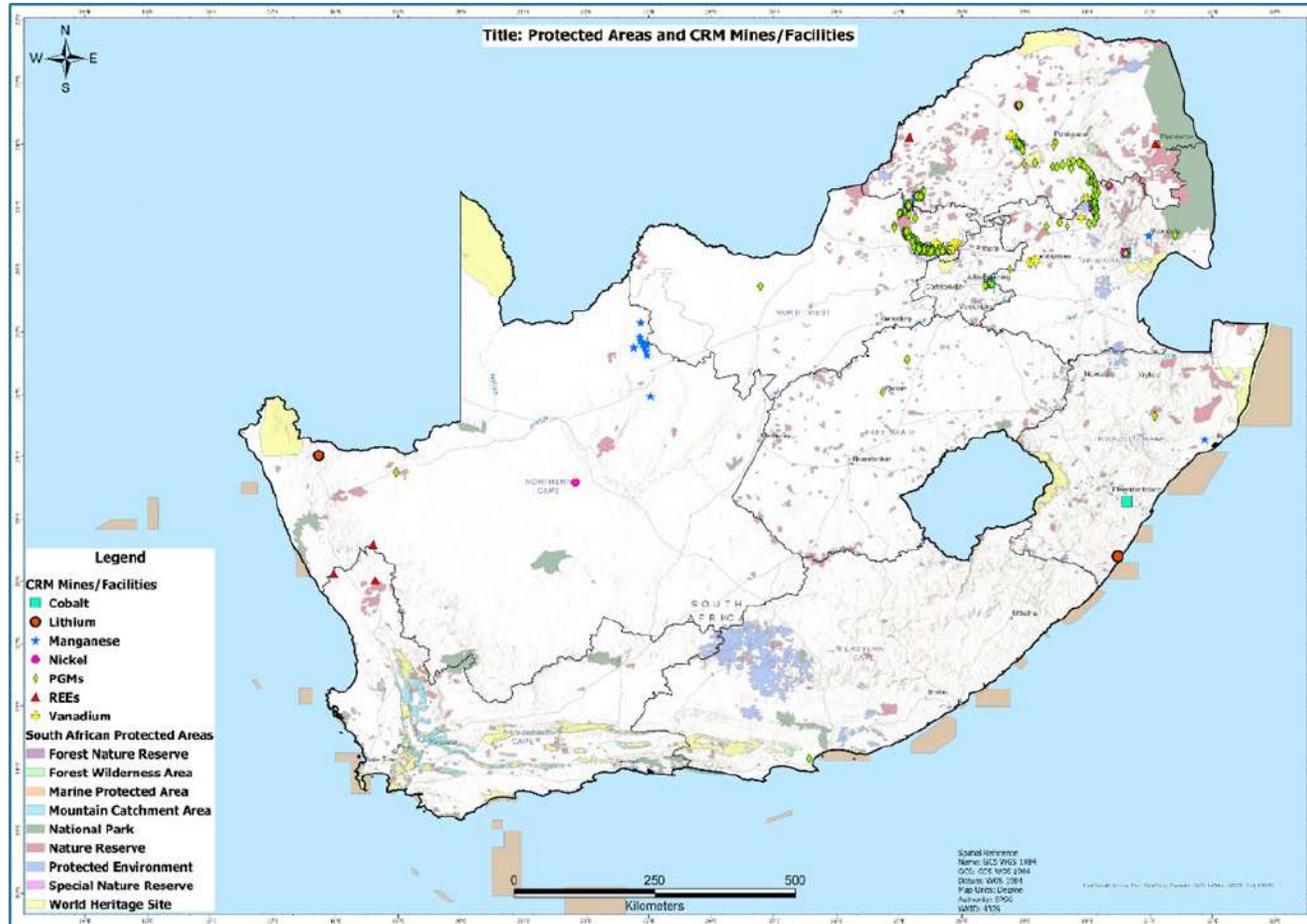
Market volatility causes job losses (e.g., PGM sector).

Mine closures

- Trigger crime, outmigration, and instability.
- Resulting hardships are often absorbed by local households.

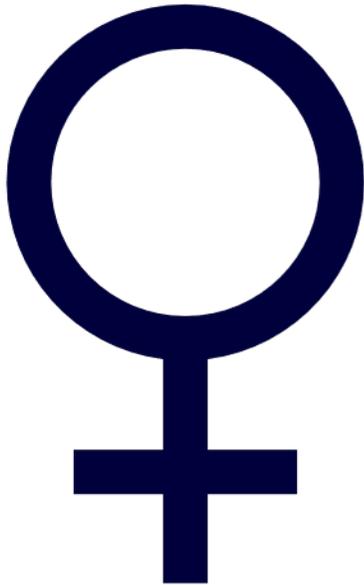


Cultural and Heritage Impact



- Proximity to Fossil Hominid UNESCO World Heritage Site raises risks of water pollution, habitat loss, and cultural heritage degradation.
- Cradle of Humankind and Sterkfontein are globally significant for human evolution and education.
- Cave sites like Sterkfontein are hydro-vulnerable (World Heritage Centre, 2011).
- Acid Mine Drainage (AMD) treatment is difficult; ongoing monitoring and management are essential.

Gendered Impacts



- High rates of IPV (45%) and NP-rape (18%) among women in mining areas like Rustenburg.
- Consequences include HIV, MDD, and limited access to healthcare services for survivors.
- Women face challenges like inadequate gear, poor sanitation, limited job opportunities, and workplace discrimination.
- Participation in decision-making is often limited; inclusion varies by company.
- Mine closure impacts are often felt acutely by women, this includes increased financial insecurity and social instability due to loss of jobs.

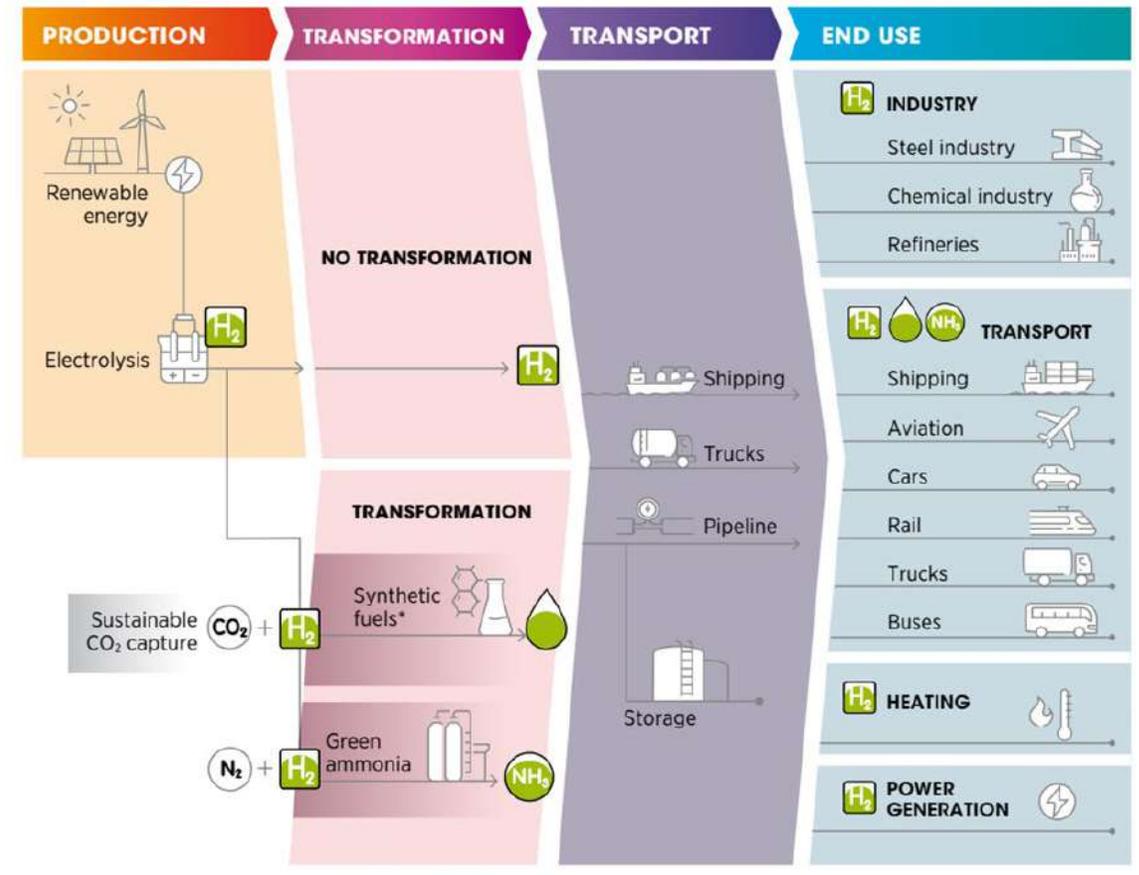
CHAPTER 8: THE SECURITY AND RESILIENCE OF CRMS SUPPLY CHAINS

A crucial upstream input into the Green Hydrogen Value chain

Critical Raw Materials



Note: CRMS have a value chain of its own



Critical Minerals Value Chain Risks & Resilience

Risks

-  **Export Inefficiencies:**
Port delays, ageing infrastructure, and poor coordination.
-  **Energy Insecurity:**
Loadshedding, outdated systems, and rising energy costs.
-  **Declining Resource Quality:**
Lack of new exploration threatens long-term competitiveness.
-  **Poor Exploration Financing:**
High risk and governance concerns deter investment.
-  **Unstable Policy Environment:**
Regulatory inconsistency reduces investor confidence.
-  **Global Market Volatility:**
Price fluctuations and trade dynamics affect revenue.

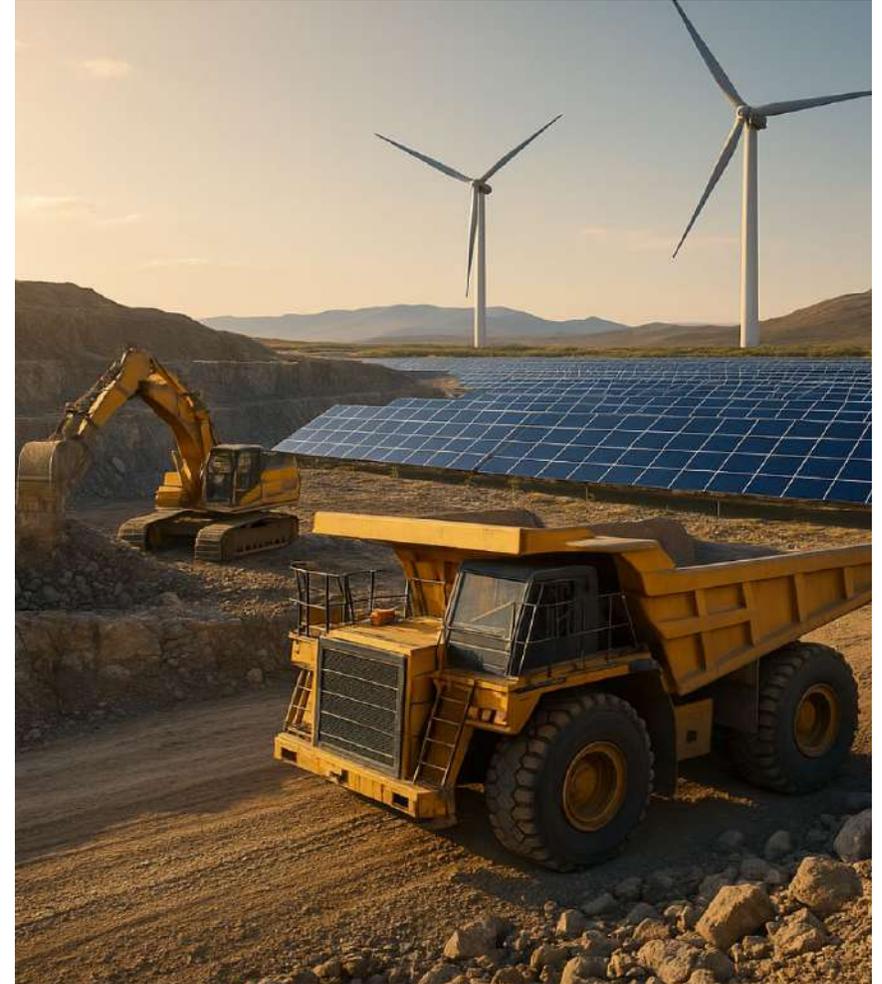
Strengthen Resilience

-  **Local Beneficiation**
Manufacture electrolyser components locally to boost industry and jobs.
-  **Electrolyser Recycling**
Recycle components to extend lifespan and support a circular economy.
-  **Support Junior Explorers**
Fund and regulate exploration to unlock new mineral resources.
-  **Regional Value Chains via AfCFTA**
Enhance trade and infrastructure for shared access to raw materials across Africa.

CHAPTER 9: SUSTAINABLE MINING PRACTICES

Transition to Renewable Energy in Mining:

- Mining companies are adopting **renewables** to cut costs and reduce environmental impact.
- **Hybrid Renewable Energy Systems (HRES)** integrate solar PV, wind, and BESS.
- **Benefits:**
 - Lower long-term operational costs
 - Greater energy reliability
 - Supports **Paris Agreement** compliance
- **Post-mining land use:** Sites converted into solar/wind farms to benefit communities and boost energy security.

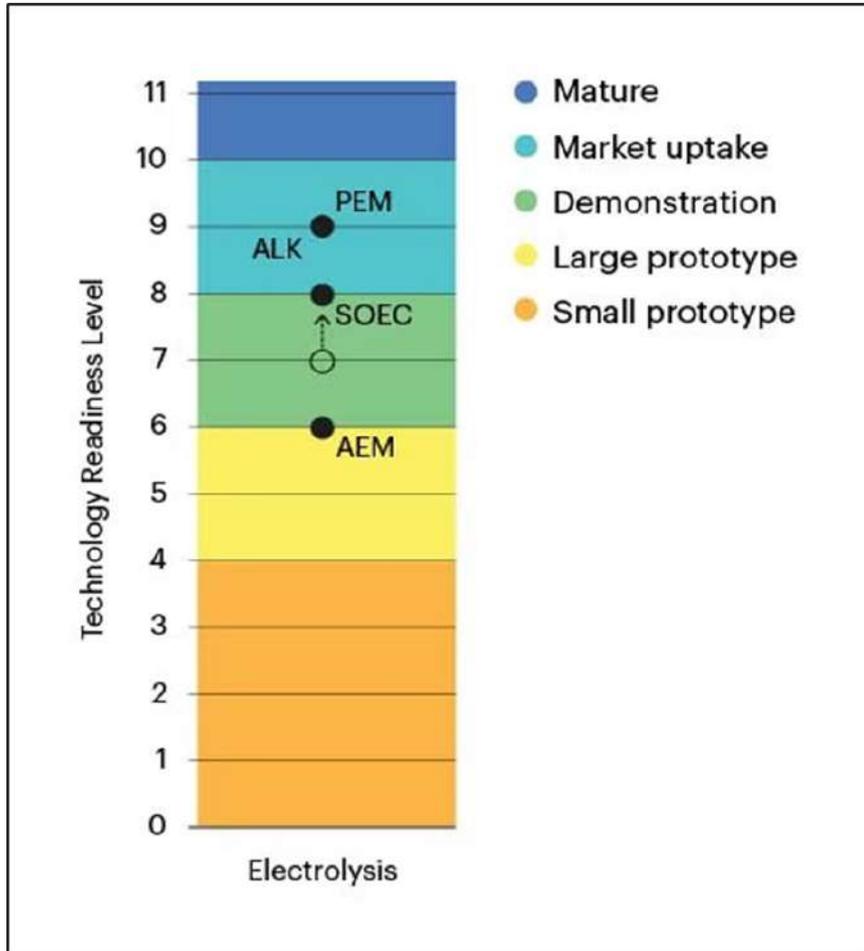


CHAPTER 10: TECHNOLOGICAL ADVANCEMENTS

Technology	Material	Electrolyser Material Requirement (tons per GW)
Alkaline	Nickel	800
	Zirconium	100
	Aluminium	500
Proton Exchange Membrane (PEM)	Platinum	0.3
	Palladium	0.3
	Iridium	0.7
Solid Oxide Electrolyser Cells (SOEC)	Nickel	175
	Zirconium	40
	Lanthanum	20
	Yttrium	5
Fuel Cells	Platinum	0.29

The table explains how much critical raw material is required for the technologies to produce a gigawatt of energy.

The Case for Technology



- Market uptake for PEM & Alkaline with entry of SOEC
- Long-term future on which technology will gain significant market share is still in doubts
- This is important as this will impact long-term CRM demand

The Role of Artificial Intelligence (AI) in Mining CRMS

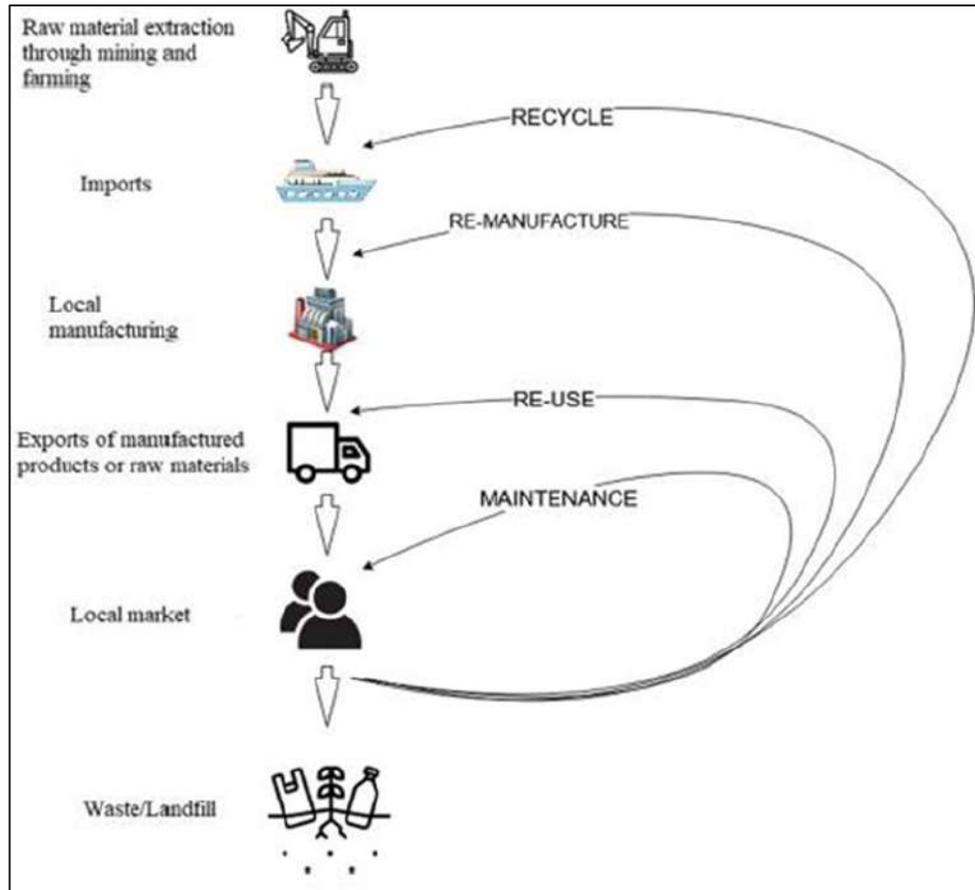


- AI improves mining efficiency, reduces waste, and enhances safety.
- Supports predictive maintenance, real-time monitoring, and exploration.
- In South Africa, AI optimizes ventilation and detects hazards (e.g., Mogalakwena Mine).
- Promotes environmental sustainability: tracks emissions, and manages water use.
- Ethical concerns: job losses vs. opportunities through retraining.

CHAPTER 11: DEPENDENCE ON CRMs - A MINERALS INTENSIVE TRANSITION

- Critical mineral supply is highly concentrated (e.g., PGMs in South Africa/Russia, REEs in China), creating geopolitical and supply chain risks for green hydrogen technologies like PEM electrolyzers.
- Technological innovation and material advances (e.g., Toshiba's 90% iridium reduction) are helping reduce dependency and build more resilient, sustainable supply chains.
- Diversifying supply sources and increasing local mining in hydrogen-focused countries can enhance reliability and reduce overdependence on a few critical minerals.
- Innovation, smarter design, and recycling are key to lowering material demand, finding alternatives to rare minerals, and supporting a circular economy.

CHAPTER 12: PROMOTING THE CIRCULAR ECONOMY THROUGH RECYCLING AND CRMs OPTIMISATION



(Hoosain et al., 2023)

- Sustainable development mandates moving away from a linear economy to a circular economy.
- Linear model has many hidden and downstream costs e.g. disposal costs, wasted raw materials.
- Emphasising less waste, more reuse and high degrees of recycling.
- A circular economy provides opportunities for improved resource efficiency, improve resource security reduced energy needs.
- Circularity should be applied at all stages of the value chain

Recycling Imperatives

- The recycling of CRMs for the hydrogen economy is crucial for several reasons:

Key Aspect	Summary
Supply Security	Recycling CRMs (REE, cobalt, lithium, platinum) ensures a stable supply for key industries, reducing dependence on imports.
Environmental Benefits	Recycling reduces harmful environmental impacts of mining, conserves natural resources, and lowers carbon emissions.
Economic Advantage	Economic benefits from reducing raw material costs, creating business opportunities in the recycling sector, and supporting the circular economy.

Global CRMs Recycling Efforts and Challenges

Europe

- EU PGM recycling supported by robust legislation and advanced infrastructure.
- Recycling infrastructure among the most advanced globally, capable of recovering >95% of PGMs from recycled materials.

Asia

- China and Japan have made significant progress in PGM Recycling in recycling infrastructure and technology.

SADC

- CRM recycling initiative in the SADC region are very few and mostly concentrated in South Africa.
- Zambia signed a MoU with the EU on the 16 March 2023 which included the promotion and investment in circular economy value chains for the recycling, reusing and remanufacturing of CRMs.

Global Challenges related to CRM Recycling

-  High economic costs and limited profitability of recovery processes.
-  Complex recovery from consumer goods like electronics and vehicles.
-  Recycling alone cannot replace the need for new resource extraction.
-  Low PGM content in products and inefficient recycling technologies hinder recovery.

South African Recycling Initiatives for Green Hydrogen

Materials Recycled	Companies recycling
Platinum (PGMs)	AST Recycling, E-Waste Technologies Africa, Mintek, SA Precious Metals, Isondo Precious Metals (IPM)
Rare Earth Elements (REE)	Desco Electronic Recyclers
Nickel	E-Waste Technologies Africa, Mintek
Cobalt	Mintek
Vanadium	Mintek
Lithium	E-Waste Technologies Africa, Veolia South Africa

South African Recycling Challenges

- Lack of Infrastructure
- Limited Legislation
- Economic and Market Challenges
- Technological Challenges

CHAPTER 13: STRATEGY FRAMEWORK FOR THE IMPLEMENTATION OF A CIRCULAR ECONOMY

For South Africa to its efforts in optimising critical minerals recycling and promote circular principles, an implementation strategy framework is crucial and should be built upon the foundation of the Just Energy Transition Implementation Plan, JET-IP. Using the JET-IP's framework and not deviating from its core ethos of socio-economic empowerment in a sustainable manner, the strategy for optimising critical mineral recycling through circular economy principles can be justified.

Potential Strategic Development Actions

- Develop a structure that complements existing public and private recycling efforts and centralises monitoring responsibilities to relevant lead institutions or stakeholders by focusing on opportunities and initiatives that are already in place.
- Define clear outcomes and impact indicators for circular economy portfolios including critical mineral recycling with country targets. Driving research and innovation into advancing recycling can assist in reaching these targets quicker.
- Establish data collection mechanisms and reporting procedures that are centralised to ensure accessible participation.
- Implement a system for regular monitoring, evaluation, and engagement with stakeholders that promotes compliance and active promotion of circular economy principles in line with socio-economic upliftment.
- Regularly review progress, identify challenges, and make necessary adjustments to the implementation plan based on the monitoring and evaluation findings.

CONCLUSION

Integrating CRMs into a Green Hydrogen Future-

- South Africa's CRMs, especially PGMs, are vital for hydrogen technologies like fuel cells and electrolyzers.
- While mining brings economic benefits (GDP, jobs, infrastructure), it also poses serious environmental and social challenges

Towards a Sustainable Transition

- Key risks include pollution, habitat loss, water scarcity, and socio-economic inequality.

Solutions lie in:

- Sustainable mining practices & innovation (AI, circular economy, recycling).
- Inclusive policies that uphold community rights and participation.
- Coordinated planning & investment in hydrogen infrastructure.
- Robust governance to balance economic, environmental, and social goals.

✓ With commitment to sustainability, CRMs mining can support a just and resilient green hydrogen transition.