Increasing Circularity in Africa's Mining Sector

Detailed Research Report

AFRICAN CIRCULAR ECONOMY ALLIANCE

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CONTENT

I. LIST OF ACRONYMS

Acronym	Description
ASM	Artisanal and Small Mining
CE	Circular Economy
COE	Cost of Energy
CSR	Corporate Social Responsibility
ESG	Environmental, Social, and Corporate Governance
GHG	Green House Gasses
GRI	Global Reporting Initiative
ICMM	International Council on Mining & Metals
LOM	Life of a Mine
LSM	Large Scale Mining
kWp	Kilowatt Peak
PGM	Platinum Group Metals
SSA	Sub-Saharan Africa
SME	Small and Medium Enterprises

II. EXECUTIVE SUMMARY

The African Circular Economy Alliance is a government-led coalition of African nations with a mission to spur Africa's transformation into a circular economy that delivers economic growth, jobs, and positive environmental outcomes. The Africa Circular Economy Alliance ("ACEA" or "The Alliance") was conceived in 2016 during the World Economy Forum on Africa in Kigali and formally launched at the COP 23 in Bonn in 2018.

By adopting CE principles, Africa's mining industry can seize opportunities to reduce costs whilst also mitigating risks associated with shifting consumer and investor preferences, and new regulations and standards:

- CE offers mining companies opportunities to decrease operating costs and increase efficiency through optimizing resources. Given that mining companies are constantly looking for ways to decrease costs and increase efficiency in order to maximize profits, adapting CE principles is beneficial to mining companies.
- CE helps mining companies respond to the global shift in consumer demand towards environmentally-friendly products and away from the linear economic model. This shift will ultimately affect the materials being used in consumer products, including materials supplied by the mining industry.
- CE provides a pathway for the mining industry to meet investor requirements on climate change and social issues. More investors are moving towards Environmental, Social, and Corporate Governance (ESG) investments, increasing the cost of capital for mining companies. CE provides a framework to ensure investor trust and access to capital as well as reputational security.
- CE provides a framework that mining companies can use to adopt comprehensive sustainability measures that can eventually guide future regulatory requirements. Given Africa's vulnerability to climate change, environmental and sustainability regulations around mining activities will become stricter in the long term. Through CE, mining companies have an opportunity to stay ahead of the regulatory curve by reviewing their practices and beginning to make changes that will allow them to transition gradually over time, rather than in sudden response to regulatory changes. Additionally, mining companies can be thought partners to governments in shaping CE policy in the long term.
- CE prepares mining companies to embrace the change of environmental standards set by global institutions. Global mining institutions such as International Council on Mining & Metals (ICMM) embrace circular economy as part of their assessments and reporting framework. ICMM made Global Reporting Initiative (GRI) reporting mandatory for members, and as of recent, the GRI partnered with the Ellen MacArthur Foundation to document companies' circularity. With increased reporting, mining companies will face internal and external pressure to adopt more CE practices.

This report outlines high-potential and actionable opportunities for the mining industry to incorporate CE principles within its operations. Additionally, an impact-feasibility assessment was conducted to determine the ease of implementation and the potential for waste reduction throughout different stages of the mining process. Opportunities discussed in the report include:

- **Reduce, reuse, and recycle waste in mining activities to maintain materials used in the system.** Opportunities to reduce, recycle and reuse resources include recycling resources, including chemicals, rocks, and other equipment, including tires, machine parts, and recycling of construction materials when rehabilitating mines. These opportunities are both feasible and high impact because they have environmental and social benefits such as reducing pollution and creating jobs.
- **Regenerate natural systems, for example, by replacing fossil fuels with renewable energy.** Mining is an energy-intensive sector and transitioning to renewable energy will decrease emissions caused by using fossil fuels. For example, the Bisha mine in Eritrea is already utilizing renewable energy. The mine has a solar plant producing 7.5MW (25% of the total power at the mine), which complements the 22MW diesel fuel used at the mine.[1]
- **Redesign mining processes and the whole mining value chain from conventional mining to circular mining systems.** This is the most impactful opportunity, however ambitious, with low feasibility due to intensive capital investments. For example, Anglo American's launch of the FutureSmart Mine program aims to transform conventional mining into more efficient mining. Anglo American seeks to use coarse particle recovery to improve energy efficiencies and water savings by 30% by 2030.

Although this report primarily focuses on opportunities for large scale mining (LSM) operations, there are also opportunities for artisanal and small-scale mining (ASM) to enter the circular economy. Like LSM, ASM activities cause environmental degradation and pollution of resources, including land and water. By applying CE principles, ASM operations can improve their environmental impact and increase their long-term sustainability. However, large capital investment is needed to improve infrastructure and acquire cleaner technologies.

To support the mining industry to enter the circular economy, government interventions will play an integral role in shaping a robust enabling environment. Key actions discussed in the report include:

- **Integrate CE in mining policies and compliance:** Governments could integrate circular economy in mining policies and articulate the industry's roadmap towards circularity. The roadmap should be clear what the government envisions the industry to become. Initiatives such as introducing transparency initiatives in value and supply chains could enhance traceability which is critical for recycling. Additionally, mining companies can be thought partners to governments in shaping CE policy in the industry.
- **Create regulatory and monetary incentives:** Governments could create policies that hold mining industries responsible for the environmental damage they cause to the environment, such as Extended Producer Responsibility (EPR). Furthermore, monetary incentives are important to support the industry throughout the transition towards circularity. These include tax cuts, subsidies, and friendly macroeconomic policies to make the transition towards circularity.
- **Formalize ASM**: About 80% of ASM are informal workers.[2] Thus, formalizing is necessary to ensure ASM's transition towards circularity as It is easier to monitor and reinforce circular principles. Formalizing ASM will increase the economic, social, and positive environmental impact of ASM as well as improve the livelihoods, particularly for women miners.

[1] Mining Technology, Going green: renewable energy projects at mines around the world, 2019
[2] Pact World, Mapping Artisanal Small Scale Mining, 2018

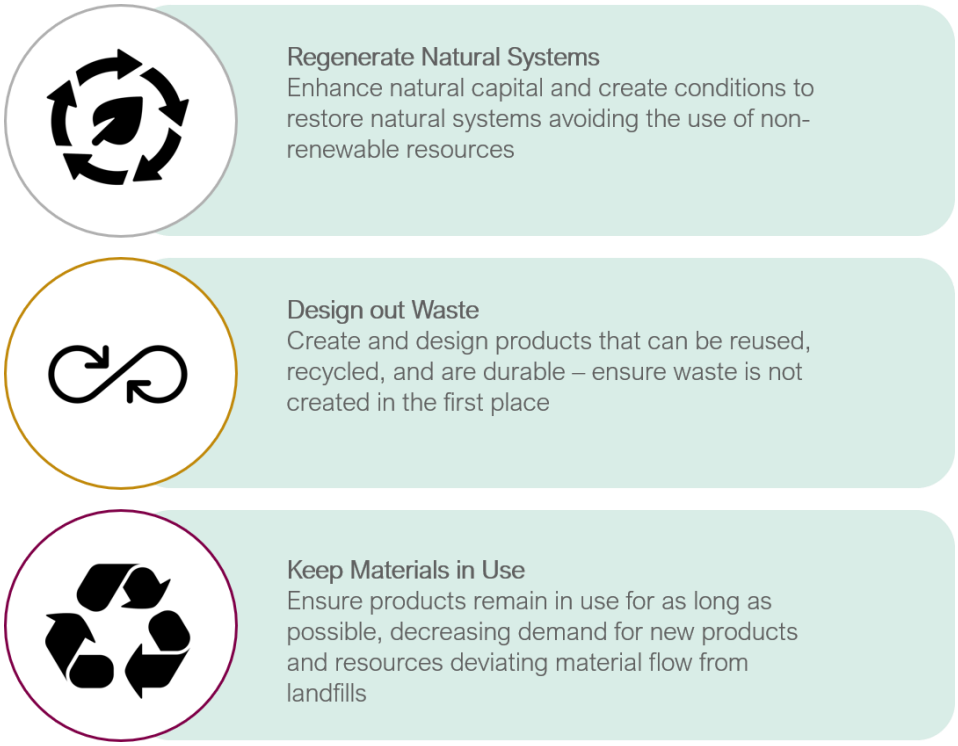
The success of CE in the mining sector in Africa will be critical to global efforts to ensure sustainable growth and has the potential to benefit mining companies through increasing operational efficiency and decreasing operational costs. CE also gives mining companies a chance to speed up decarbonization and emission reduction efforts and meet regulatory and governmental goals. Some key enablers to the transition to CE are enabling policies, incentives and ASM formalization.

III. INTRODUCTION

The current global linear economic model is unsustainable, creating risks for businesses, governments and communities globally. The current linear economic model - take, make, and dispose of materials - is a risk to businesses, governments and communities as it is causing an increase in material extraction and waste generation. Today, societies and industries around the world consume over 100bn tons of material goods (e.g., minerals, fossil fuels, ores, and crops and trees); however, only 33% remained in use after a year, while 63% is discarded either through emitted gasses or dumped into the environment and landfills. Unlike the linear economy, circular economy (CE) aims to recover value from waste, reduce the extraction of materials, and ultimately design an efficient system where nothing is lost.

Shifting towards CE is an opportunity for businesses and governments to create new economic opportunities, whilst providing social and environmental benefits. CE is an economic system that aims to separate economic growth and the surge of resource consumption. Material resource consumption is expected to double by 2060. However, available resources are finite. CE offers an opportunity to tap into existing materials in the system and recover value from waste to meet future demand. New economic prospects, business models, and markets are emerging through CE principles to complete the transition for businesses and governments.

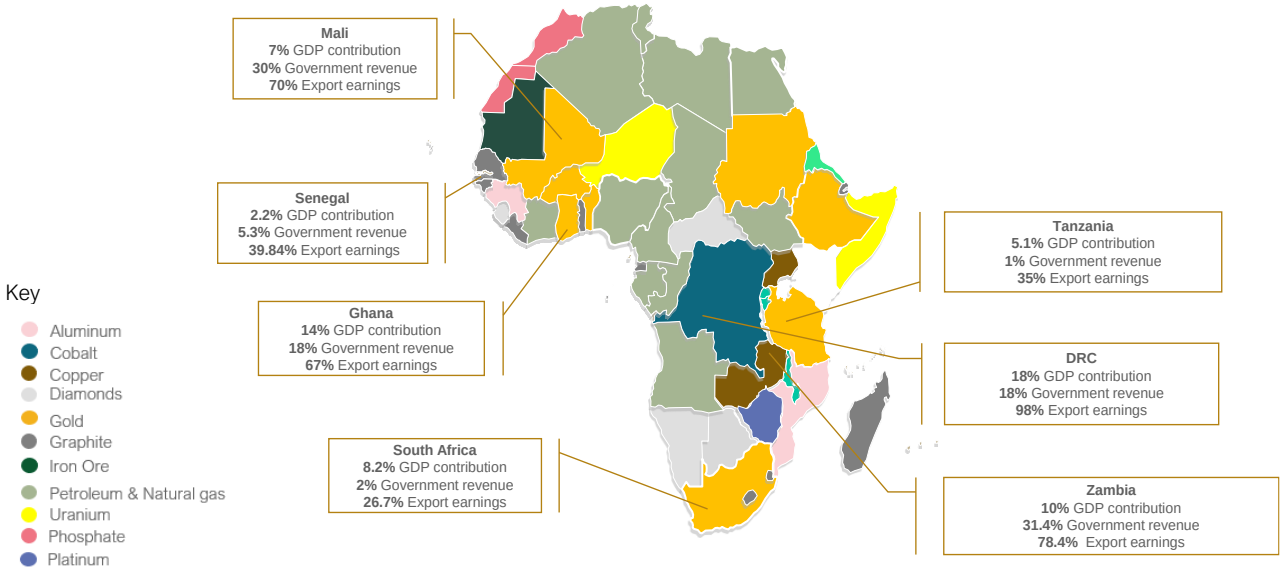
Figure 1: Principles of Circular Economy [3]



Given the economic contribution of mining to African countries, CE would significantly contribute to creating a sustainable mining industry. For countries that depend on mining as the primary economic activity, mining contributes considerably to their foreign earnings. For example, Botswana mining accounted for roughly 85% of national foreign exchange earnings, 33% of government revenue, and 25% of GDP for the past four decades.[4] In many countries, mining activities contribute to Africa's economy through export and government earnings. Given the economic contribution of mining to African countries, the mining industry has a critical role to play in supporting the transition to a circular economy.

[3] MacArthur Foundation, Circular Economy, 2021
[4] Export.gov, Mining in Botswana, 2019

Figure 2: Minerals distribution and economic contribution in Africa



EITI. Minerals Summary Data, 2021
Tanzania Invest, Exports, 2021
World bank, World bank Supports Mali, 2019
Al Jazeera, Mapping Africa's natural resources, 2018

Further, as demand for minerals and metals grows, adopting CE principles can support the mining industry to adapt to increased pressure on limited resources. Minerals and metals are consumed in everyday commodities such as cellphones, cars, household appliances, and machinery. As the global population increases, so does the consumption of materials. This will consequently increase the exploration and exploitation of minerals in Africa, and lead to the growth of the mining sector. The mining sector has an interest in transitioning to CE to meet growing demand.

This report outlines the current state of mining in Africa, reasons why mining companies should care about CE, our approach to identifying CE opportunities, CE opportunities that mining companies and governments can support, a brief overview of artisanal and small-scale mining (ASM), as well as policy interventions to enable the mining industry transition to CE.

IV. THE CURRENT STATE OF MINING IN AFRICA

Mineral Extraction in Africa

The mining sector in Africa comprises medium and large companies, as well as artisanal and small-scale miners (ASM). There are several large mining operations in Africa run by international companies through joint ventures with governments. Multinational firms from Europe, North America, and recently China dominate mining operations in Africa. Many of the biggest mining companies in the world operate in Africa, including Anglo American, Rio Tinto, AngloGold Ashanti, Barrick Gold, and BHP Billiton. These large-scale operations tend to be highly mechanized and capital-intensive. In contrast, ASM comprises

mostly of informal miners characterized by low mechanization, labor-intensiveness, and sometimes illegal operations.

Africa has a rich mineral and metals endowment with a strong current and future exploitation potential. In the Southern region, South Africa, Botswana, and Zimbabwe are the main extractors, producing mostly Platinum Group Metals (PGMs), Diamond, and Copper. The Copper belt extends from northern Zambia to central Africa in southern Democratic Republic of the Congo (DRC). The eastern region extracts mostly Gold from Tanzania, as well as Copper and Cobalt from Burundi. With 30% of the world's mineral reserves and large Cobalt reserves, Diamonds, Platinum, and Uranium, Africa's mining activities are set to increase with time.

Table 1: Mineral classification by International Council on Mining & Metals (ICMM)

Category	Minerals
Ferrous alloy	Iron, Chromium, Cobalt, Manganese, Molybdenum, Nickel, Niobium, Tantalum, Titanium, Tungsten, Vanadium
Non-ferrous alloy	Aluminum, Antimony, Arsenic, Bauxite, Beryllium, Bismuth, Cadmium, Copper, Gallium, Germanium, Indium,
Precious metals	Gold, Platinum Group Metals (Palladium, Platinum, Rhodium), Silver
Industrial metals	Asbestos, Baryte, Bentonite, Boron Minerals, Diamond (Gem/Industrial), Diatomite, Feldspar, Fluorspar, Graphite, Gypsum and Anhydrite, Kaolin (China-Clay), Magnesite,
Mineral fuels	Steam Coal (incl. Anthracite and Sub-Bituminous Coal), Coking Coal, Lignite, Natural Gas, Crude Petroleum, Uranium

Gold, Copper and Diamonds are the most commonly mined minerals in Africa's mining industry and make a significant contribution to Africa's economy:

- **Gold mining is significant to the African mining industry as 34 out of 54 African countries mine this mineral**. The total Gold export value in Africa was about USD 50B in 2018, the highest of all mineral exports, excluding natural gas and crude petroleum.43 Gold is used in jewelry, technology, and it also serves as a benchmark for financial markets by central banks and investors. This diversity of uses of Gold makes it one of the most sought-after minerals in the world. Due to its footprint in many countries in the continent, circular economic opportunities in Gold mining have a great potential for improved socio-economic outcomes and industrialization of the continent.

- **Copper is one of the minerals used in electrical equipment, and as the world moves towards a low-carbon energy future, the demand for Copper could rise tenfold by 2050.**[5] In Africa, DRC and Zambia are the largest extractors of Copper. In 2019, DRC extracted about 1.3 million MT of Copper while Zambia extracted about 790,000 MT of Copper.[6] The global shift towards a low-carbon economy will increase the demand for electronics, electric vehicles, renewable energy, and energy efficiency, which require Copper as input for storage batteries. For example, electric

[5] Copper Alliance, How will the future demand be met, 2019
[6] Copper Investing New, Top Copper Production by Country, 2020

vehicles require three to four times as much Copper as internal combustion engine vehicles due to their use of batteries to store energy.5

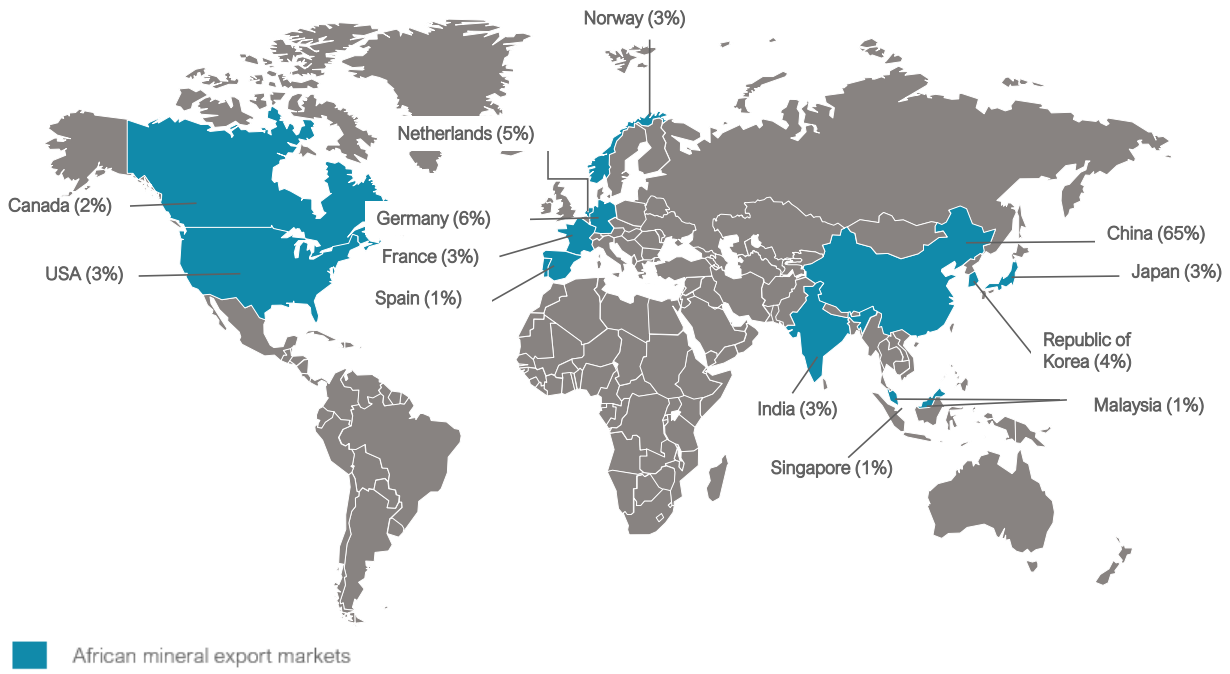
- **Diamond is one of Africa's most mined minerals especially in the southern region.** Diamond extraction contributes about USD 8B to Africa's economy, and approximately 47% of the world's diamonds come from the continent.[7] The total export value was approximately USD 13B in 2018, the second highest of all mineral exports, excluding natural gas and crude petroleum, in the continent.[8] Diamonds are mostly used as a precious mineral due to their hardness; they are also useful in industrial processes.

Markets

Key trends in global mineral markets are driving the demand for Africa's minerals. The top markets for ores, slag, and ash exported from Africa include China, Germany, Netherlands, Korea, Japan, U.S., and India (see Figure 3).[9] The rise of industrialization in China and India as well as technological advancements have driven increased demand for mineral exploration and extraction in Africa over the last decade. Over the coming decade, the demand for green infrastructure in the Global North is also set to increase demand for minerals such as Copper, Cobalt, and other industrial minerals. Since most markets for Africa's minerals and ores are in the Global North, the change in demand and market forces are more likely to expand the offtake of minerals from the continent, particularly those needed for a low-carbon economy.

[7] The Diamond Reserve, Just how important is Diamond to Africa's Economy, 2020
[8] Ibid
[9] Trade Map, Export Mineral, 2021

Figure 3: Export markets of ore, ash, and slag from Africa to other countries[10]



Mining Outlook and Challenges

Inadequate infrastructure, particularly clean energy for mining, is a challenge that could hinder the shift towards low carbon emissions in the mining industry. Access to reliable energy is one of the most significant challenges for the mining industry, forcing most mining companies to use fossil fuels such as coal and diesel as the primary energy source for mining operations. Although coal and diesel are crucial to energy generation, coal-fired electricity generation accounted for 30% of global CO_2 emissions.[11] As such, companies are under increasing pressure to shift away from coal as their only source of energy and to begin to explore more renewable options.

"Coal remains the key source of energy in mining, especially in the smelting of minerals. There is a need to generate affordable and reliable energy alternative for mining" – Mining Sustainability Expert

Further, conflicts with local communities continue to pose risks to the mining industry. Mining activities can cause considerable disruption despite being able to create new communities and bring wealth to existing communities. Disruption comes from unevenly shared benefits, the loss of existing livelihoods, and the damage to their environment and culture. These disruptions can lead to social tension and sometimes to violent conflict. To regulate these conflicts, governments and international initiatives have developed different compliance guidelines to regulate the industry and ensure sustainability in the mining sector. Government regulations include guidelines on reducing land and water pollution as well as carbon emissions. International initiatives are also taking shape to minimize mining's environmental and climate footprints. Initiatives include the World Bank's Climate-Smart Mining Initiative, ICMM, Global Reporting Initiative (GRI), and the Environmental, Social, and Corporate Governance (ESG) criteria.

[10] Ibid.
[11] IEA, Global Energy & CO_2 Status Report, 2019

Adopting CE principles could support the mining industry to address these challenges by ensuring adequate clean energy infrastructure and reducing disruptions in mining towns. Mining companies are already active in meeting sustainability and environmental compliance to conserve the environment. Most mining firms prepare sustainability reports and articulate efforts to reducing waste, minimizing resource consumption, and reducing environmental pollution. Fortunately, the CE lens builds on current sustainability strategies to comprehensively move the whole industry towards eliminating waste from the industry's initial stage and throughout the Life of a Mine (LOM), rather than cleaning up waste that the sector has already created.

V. WHY SHOULD MINING COMPANIES CARE ABOUT CE?

"The main drivers of circular economy in mining are OPEX cost reduction, influence from interest groups and external investors, as well as the company's vision to be a responsible miner by decreasing environmental impact." - Mining Sustainability Expert

CE offers mining companies opportunities to decrease operating costs by increasing operational efficiency. CE aims to optimize resource use, which is significant for the mining sector, as natural resource scarcity increases. Therefore, designing efficient systems that utilize the CE principles will reduce consumption intensity and the cost of sourcing resources, consequently decreasing the industry's OPEX and its carbon footprint. This is evident with Syama Gold Mine's switch to renewable energy from its existing source of power, a 28 MW diesel generator. The mine signed a 16-year contract for a hybrid (solar, thermal, batteries) power plant with Aggreko. In 2020, Syama Gold mine's cost of electricity (COE) decreased by 40% and CO_2 emissions by 20%, delivering a life-of-mine[12] all-in sustaining cost of US$746/oz.

By adopting CE principles, mining companies can align with the global shift of consumer demand towards environmentally-friendly products and away from the linear economic model. Consumers are deciding to transition towards low-carbon supply chains in various sectors, including mining. In 2020, Apple announced that they plan to become carbon-neutral by 2030. The company also envisions sourcing materials that follow a circular supply chain model, thus eliminating their reliance on mining and setting stricter sourcing requirements.[13] With 14% of the global smartphone market share,49 Apple's carbon-neutral goal could force the mining industry to transition towards a low-carbon circular operation model. Therefore, mining companies have an opportunity to stay ahead of consumer preferences and build future resilience in the marketplace.

Following CE principles provides the mining industry with a pathway to meet investor requirements and ensure financial and reputational security. Investors in the mining sector are increasingly paying attention to other issues beyond finances, such as climate change and social issues. This has caused a surge of ESG investments, estimated to hit USD 1B this year.[14] Beyond this, low-carbon-footprint commitments are shaping investment decisions. These shifts in investments have squeezed funds for the mining

[12] Aggreko, Worlds largest offgrid mining hybrid power system, n.d
[13] Apple, Environmental Progress Report, 2020
[14] Bloomberg, Spending on ESG Data Seen Rising, 2020

industry. CE principles complement ESG ratings, considering factors such as resource consumption, renewable energy, waste generation, and responsible sourcing.

CE provides a framework that mining companies can use to adopt comprehensive sustainability measures that can eventually guide regulatory requirements. Currently, most governments across Africa have compliance guidelines that mining companies must follow. For example, in Ghana, holders of a mining lease need a mine closure plan and must rehabilitate a mine within 12 months of closure. South Africa requires mines to provide sufficient financial provision, assessed annually, to cover rehabilitation costs. Considering the continent's vulnerability to climate change, environmental and sustainability regulations around mining activities are set to be strengthened in the long term, creating a potential risk for mining companies. Likewise, 30% to 50% of Copper, Gold, Iron ore, and Zinc are concentrated in areas such as South Africa, where water stress is already high.[15] Such risks could increase regulations and laws around mining activities as governments strive to conserve finite resources such as water. However, CE can mitigate these risks by minimizing resource consumption and waste production, which in return support mining companies to adapt to and shape regulatory requirements. The mining industry can evolve towards being a thought partner to governments on developing CE policy and regulations given their ability to research and test initiatives and cross-continental presence.

Through CE, mining companies are prepared to embrace the change of environmental standards set by global institutions. International Council on Mining & Metals (ICMM) is part of the Global Reporting Initiative (GRI) and has committed to adding the CE to the reporting framework. Recently, the GRI launched the "GRI 306: Waste 2020" – this is the first globally applicable reporting standard for companies to provide a complete picture of waste impacts along their value chain. In partnership with the Ellen MacArthur Foundation, the two institutions have created the Circulytics – a tool that enables businesses to assess circular economy performance in operations. They also created the GRI 306 linkage document to provide an overview of the GRI Waste Standard disclosures and maps them against the relevant Circulytics indicators. Although not yet mandatory, such global shifts will impact all GRI community members, including mining firms. Therefore, mining companies should start considering the circular economy lens in assessing operational efficiency.

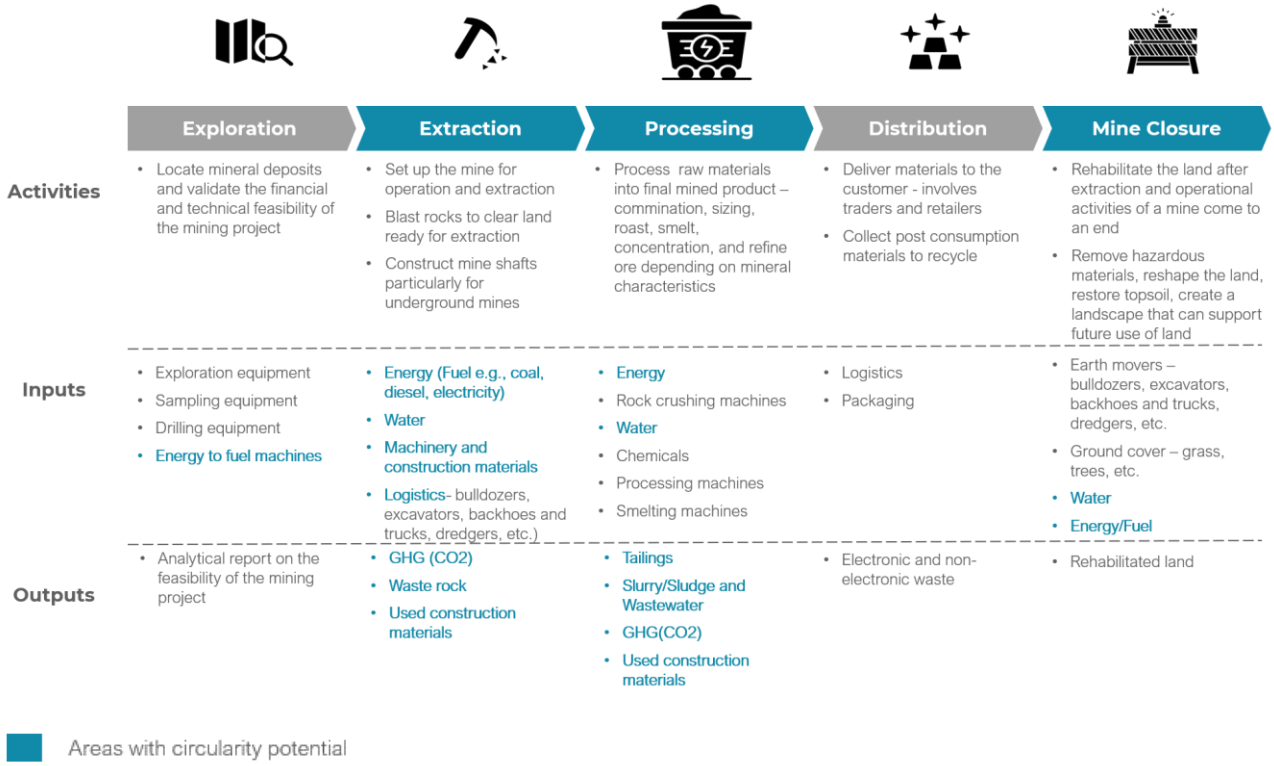
VI. OUR APPROACH TO IDENTIFYING CE OPPORTUNITIES

Although artisanal and small-scale mining (ASM) presents circularity potential, this paper focuses on formal mining by large to medium mining enterprises. This is because large companies use the most resources, have the largest footprint in terms of size, generate the most waste, and have the resources to lead the transition towards CE in partnership with national governments. Opportunities discussed can be adopted to ASM; however, the sub-sector must be formalized to shift towards circularity effectively. ASM is discussed further in section VIII.

This report investigates circular opportunities through mapping the Life of a Mine (LOM) to articulate key areas for circularity potential. Figure 4 below summarizes key activities, inputs, and outputs in each mining process stage. The highlighted ribbon on the LOM and highlighted text indicates areas where the most resources are consumed, and most waste is generated.

[15] McKinsey & Co, Reimagining Industrial Operations, 2020

Figure 4: The Life of a Mine mapping potential areas for circularity



An impact-feasibility analysis was conducted to evaluate and highlight the most actionable and impactful opportunities the mining sector can take to transition towards circularity:

- **Impact** is defined as reducing emissions and waste, reducing consumption of virgin resources, and creating employment opportunities.
- **Feasibility** is defined as the ease of implementation. Factors that were assessed include the low cost of implementation and existing momentum (the presence of ongoing initiatives, either policies or business models to change CE). Accessibility of resources to implement the opportunity was also assessed.

Each of the three criteria for impact and feasibility has a maximum value of one, and continuous scoring was used to determine an opportunity's position on the impact-feasibility matrix—an example of how the scoring works can be seen in Figure 5 below.

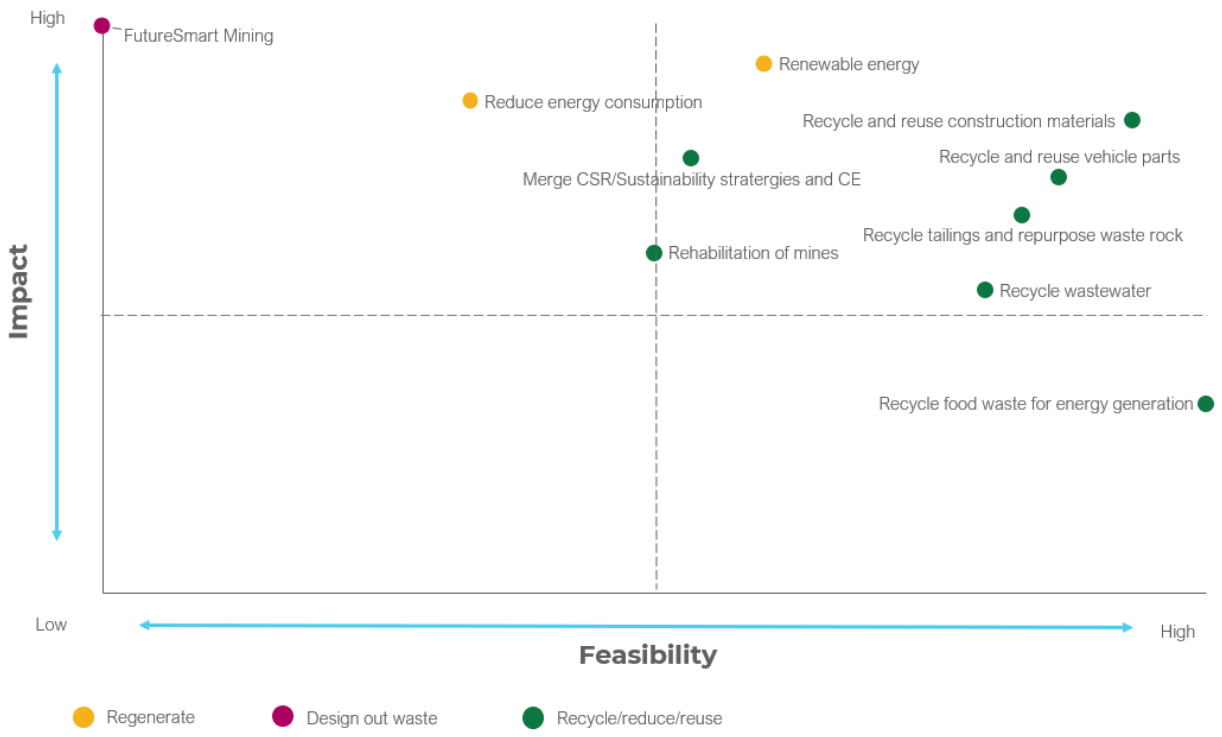
Figure 5: Example of impact-feasibility assessment

Opportunity	Impact			Feasibility		
	Reduce emissions or waste	Reduce consumption of virgin materials	Create jobs	Low cost of implementation	Already undertaken (momentum)	Accessibility of resources
Renewable energy	1	0.8	1	0	1	0.8

VII. CE OPPORTUNITIES IN MINING

Multiple opportunities were identified for the African mining industry to engage with the three CE principles; i) recycle/reduce/reuse resources and waste, ii) regenerate natural resources, and iii) design out waste. Our analysis shows that reducing resource consumption, recycling, and reusing resources are the most impactful and highly feasible opportunities as there are already stakeholder interests in those opportunities. In figure 6, redesigning out waste, labeled as FutureSmart Mining, is an ideal opportunity to pursue. However, the ease of implementation (feasibility) is low as the initial capital investment is high.

Figure 6: Impact-feasibility matrix showing the CE opportunities in mining



Recycle/reduce/reuse resources and waste

Recycle wastewater

Like energy, water is a resource that is extensively used in mining operations. Water is primarily used to process minerals, transport slurry, suppress dust, and fulfill employee needs. In South Africa, the mining industry is the second-largest water user right behind agriculture; therefore, mines could significantly impact water savings.[16] Proper management of clean water and wastewater is key to maintaining supplies of this resource. The total annual water consumption of mines can be up to 30,418 megaliters of water annually.[17] This is equivalent to the amount of water needed to feed 54% of Africa's population in a day.[18]

Company: AngloGold Ashanti, Ghana
Case: Water treatment plant
Impact: 81% water recovery
In 2014, AngloGold Ashanti contracted Veolia Water Technologies (VWT), a leading specialist in water treatment, to operate and maintain a water treatment facility in Iduapriem opencast mine in Ghana. AngloGold Ashanti recovered 81% of wastewater. This recovery also met the full compliance (100%) with the discharge limits set by the Ghanaian environmental protection agency in (EPA).

Recycling, reclaiming, and reusing wastewater to reduce water consumption in mines is key to lowering mines' resource intensiveness. Uptake of water can be reduced if the mines' wastewater is recycled, reused, concentrated, and reclaimed. Mining companies can improve wastewater management in three ways: lining waste and tailings dams to avoid water seepage, put wastewater in tanks to prevent evaporation, and filtering water from slurry/sludge/tailings before storing the waste in dams.[19] Mining companies reclaim water using water treatment plants that help mines reuse water from tailings dams to ensure sustainability as this resource is scarce and to fulfill their compliance requirements. Innovations are taking place to move towards waterless mining so that mines can reduce water intake. Anglo American is developing a technology that will close the loop by creating a sealed system that increases efficiency and directs water recycling and reuse.[20]

Recycle and reuse vehicle parts

Given the mining industry's high reliance on transportation, there are many opportunities for adopting CE principles by recycling and reusing vehicle parts. Vehicles in mines include fleet trucks, planes, earthmovers, conveyor belts, fleet trucks, mostly used to move supplies, loose soil, and minerals from the mine to customers. The trucks usually have massive tires that are 30 cm. thick and with steel content weighing up to 800 kg. Tires are said to be one of the top-five cost drivers for miners.[21] Usually, tires cost USD 15K-18K on average, and all six tires on a fleet truck need to be replaced at least every

Company: Kal Tire, Australia, Chile,
Case: Tire Recycling
Kal Tire uses an ultra-repair technology to repair scrap tires. The process involves using patches to replace the steel belts in the tire and restore it to its original strength and integrity. The company also uses thermal conversions to recycle tires to recover steel wire, carbon black, and fuel oil. Kal Tire ensures that 100% of the tire can be reused.

[16] Theresa M Askham et., Water Sustainability of Selected Mining Companies in South Africa, 2017
[17] Anglo American, Annual Report, 2019
[18] In Africa, household water use averages 47 liters/person, FAO, n.d.
[19] Dalberg Interviews, 2021
[20] Anglo American, Picture this: The Waterless Mine, 2021
[21] Mining[Dot]Com, Tires are a top five cost for a miner, 2016

month.[22] Given a high turnover, waste tires are an issue that recycling industries could resolve. Similarly, recycling and reusing scrap metals and other vehicle parts can be another opportunity.

Repurpose waste rock

Different types of mine, both open-pit and underground mine, drive land disturbance, which can harm natural biomes. The process of making an open-pit or an underground mine disrupt natural biomes of the area. Given that open mines could cover about 4 – 60 meters wide, while underground mines could 100-140 meters below sea level; a lot of harm is done to natural biomes. More than 50 megatons of waste rock could be generated during this process, and tailings could add up to 30 megatons.[23]Since waste rock and tailings storage and disposal require large areas of land, natural biomes in the respective land is harmed. Repurposing waste rock can ensure that less land is used for storage and disposal, and in return, less harm is done to natural biomes.

Non-acidic forming (NAF) waste rock can be reused by mining companies during mine closures, and in other industries such as construction industry. Waste rock can be used as backfill, landscaping, and as an input for construction materials for roads and feedstock for concrete for construction. Potentially Acid Forming (PAF) waste rocks could neutralize alkaline agrarian soils for agricultural purposes.

"Sustainable mining is on the trend; mining companies are constantly thinking on designing and upgrading their waste treatment to reclaim value especially from waste rocks, and tailings dams" – Metallurgy Expert

Recycle and reprocess tailings

Effective tailings management is critical to reduce the environmental impact of the mining industry. Tailings are formed after the mined ore is crushed, grounded, and processed. They are by-products of the mineral recovery process, usually in the form of slurry made up of fine mineral particles. Tailings are typically stored in large dams that could extend to approximately 1,000 hectares. If not well-managed, they could leach into water resources and cause significant water and land contamination. In research conducted by Reuters, South Africa is said to have the largest number of high-risk tailings dams.

Company: DRD Gold, South Africa
Case: Reprocessing Tailings
DRD Gold is one of the first SA companies to reprocess tailings to obtain minerals. It is the only company in SA focused solely on retreating tailings. The company uses high-pressure hydromechanical mining. The technology enables DRD Gold to recover 40% of minerals from tailings.
In 2020, the group produced a total of 5234 kg of Gold worth nearly USD 288M.

Reprocessing tailings to extract valuable mineral material is an opportunity for mining companies to retrieve leftover minerals and reduce tailings waste from the environment. In most mining countries, tailings are considered waste as they have low-grade ore. However, as minerals' scarcity increases and technology advances, tailings become a significant resource whose value can be retrieved. Additionally, the tailings can be reused outside of the mining industry, primarily in construction and agriculture. For

[22] Dalberg Interviews
[23] Anglo American, Sustainability Report, 2019

example, Manganese tailings are used in agroforestry, glazes, glass, and building and construction materials.[24]

Recycle and reuse construction materials

Recycling and reusing construction materials is an opportunity for mining industries to save on importation costs. When creating underground mines, construction materials such as iron materials and wood/timber are used to hold up the earth's surface for safety. Other construction materials that can be recycled/reused are pipes and conveyor belts, including machines to transport ores from the ground. Construction material waste presents an opportunity to create recycling industries that will either upcycle or downcycle this waste that can be sold back to the mines or other markets outside the mine. Since these recycling industries will be local, mining companies can save on importation costs by obtaining some of their construction materials locally.

Merge CSR/sustainability strategies and the CE framework

CE could complement Corporate Social Responsibility (CSR) strategies to increase the impact that mining has on the community by partnering with SMEs to create circular business opportunities. CSR and CE align in a way that they both aim to benefit not only the company but also all stakeholders involved. Thus, CE combined with CSR can contribute to strategic business improvement and develop sustainable business processes and community engagement. Given different CE opportunities in mines, engaging SMEs in some CE projects could improve livelihoods and share knowledge and expertise with local communities. For example, mining companies could partner with SMEs/entrepreneurs around the recycling community to recycle tires, scrap metal, and construction materials from the mine. Products refurbished or recycled could be sold back to the mining companies or external markets.

Rehabilitate mines for economic development

Strategically rehabilitated mines can offer an opportunity to regenerate mining grounds to their natural state or reuse the mining grounds as an economic opportunity. More initiatives are being taken to restore the mining landscape by reusing waste rock in rehabilitation. Mines use waste rock with cement to fill mining cavities. However, the mining industry is putting forward more innovative thinking to rehabilitate mines for economic development. For example, in North Queensland in Australia, the Kidstone renewable (solar and hydro) energy hub was developed on the historical Gold mine site reusing two open pits with different elevation levels as part of energy generation and storage. Some mines have been converted into gardens and others as touristic attractions. For example, Butchart garden was once a limestone quarry, but it is now known as Sunken Garden, has a designation as Canada's National Historical site, and attracts over 1 million visitors a year.[25] However, mines could operate for 10-30 years or more. Thus, progressive land rehabilitation must be used to reduce the cost of restoration and the impact of land disturbance.

Recycle food waste for energy generation

Given that mining companies can employ thousands of employees, there are numerous opportunities to address food waste, including recovering value with promising activities in converting waste-to-energy and soil enhancers/fertilizer. Mining companies can employ thousands of employees depending on the mining operations' size. These employees range from laborers to engineers to security personnel. In remote mining areas, large to medium scale mines are housed and fed by mining companies using food

[24] ICMM, Mining and metals and the circular economy, 2016

[25] Butchart Gardens, Our Story, n.d

services providers such as Sodexo[26]. Foodservice providers produce food waste, both pre-consumer (in the kitchen) and post-consumer (food not eaten)[26]. There are opportunities to convert food waste into resources such as energy. Biomass energy is a high potential CE opportunity to address food waste and energy challenges. Over 80% of the SSA population relies on either wood, crop, or animal residues in meeting households.[27]

Regenerate natural resources

Use renewable energy and reduce energy consumption

Energy is one of the most consumed resources in mining. Energy is consumed throughout the mining process, from exploration to processing the final product. The mining industry uses energy from diesel, electricity from the grid, and some have started transitioning to renewable fuels to run large machines, generators, and vehicles. Large mining companies such as Glencore could use up to 210 petajoules of energy annually.[28] This is equivalent to the energy consumption of ~12.7 million people in Africa.[29] With a high energy consumption, mines generate high carbon emissions.

Mines can integrate renewable energy such as solar and wind energy to power mining operations to regenerate natural systems. Mines across the continent have started using renewable energy. Moreover, compared to traditional diesel-powered generators, renewable energy is cheaper and produces less CO_2 emissions. Syama Gold Mine in Mali switched from its existing source of power, a 28 MW diesel generator. The mine signed a 16-year contract for a hybrid (solar, thermal, batteries) power plant with Aggreko. In 2020, renewable energy reduced the cost of electricity (COE) by 40% and CO_2 emissions by 20%. The project also has a 10 MW battery storage system that provides spinning reserve displacement and outbalances sudden jumps in load. Battery storage systems are at the core of ensuring processing plants run at minimal disruption, which impacts the availability and reliability of machines as well as efficiency in mining activities.

Company: Shanta Gold Ltd, Tanzania
Case: Renewable energy rental
Impact: Saves 219,000 liters of fuel and 660 tons of CO_2 per year.

In 2014, Shanta Gold Ltd contracted Redavia, an independent power provider, to install eight rental solar power plants that provide 674kWp that saves 219,000 liters of fuel and 660 tons of CO_2 per year.

The fixed price rental contract stabilized Shanta's costs by reducing power costs volatility, reduced local pollution, and visibly embodied Shanta's commitment to mining responsibly and increasing its operational efficiency.

"The upfront capital of investing in renewable energy is high. Thus, investors need to capitalize on non-mining companies that can lease services to mining companies." - Metallurgy Expert

[26] Sayannyambuu, Mandakh-Erdene, An evaluation of mining camp food waste management practices in Canada: an overview, 2020
[27] ACEA, Circular Economy Market Research, 2020
[28] Glencore plc. Annual Report, 2019
[29] UN Department of Economic and Social Affairs, ENERGY STATISTICS POCKETBOOK 2018, 2018

Independent operators and entrepreneurs in this space can take advantage of the opportunity to become service providers to mining companies. This has been a successful model for some mining companies, such as Shanta Gold in Tanzania. This could mean an opportunity to support local enterprises, create jobs for mining communities, reduce carbon emissions, and ensure the license to operate.

Design out Waste

Design Circular Mines

An aspirational solution to reducing resource consumption and recycling waste is designing smart mines with the environment in mind. Rather than investing in diesel generators for energy, new mines can invest in renewable energy such as solar and wind. In terms of water management, new mines can employ technologies to eliminate water usage in mines. This would be most feasible for upcoming mining projects in the continent.

"Since circularity requires heavy investment for existing mines, we need to intervene in upcoming mining projects, e.g., Kabanga Nickel Mine in Tanzania, and influence the firm to think of circularity measures from the get-go." - Mineral Processing Expert

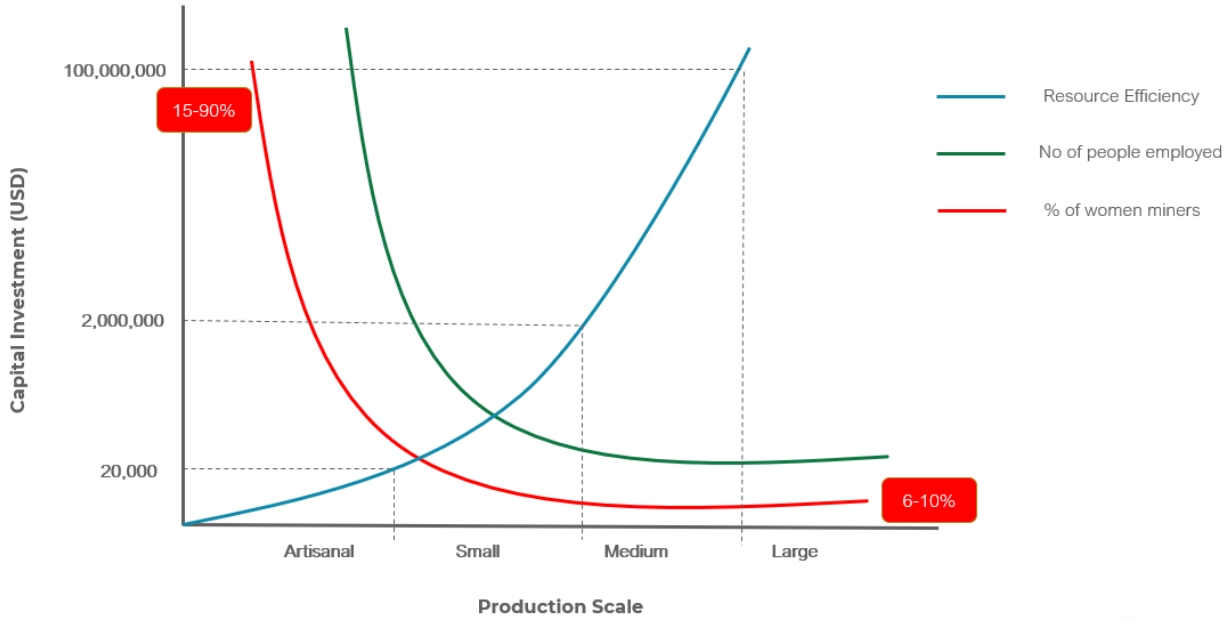
Some companies are already putting redesigning mining operations into consideration. Anglo American is currently investing in exploring a FutureSmart Mine that will be circular, save costs, increase efficiency, and ease mines' operations.[30] Further, international organizations such as the World Bank have started conversations with mining companies to ensure that extraction of minerals is done at a minimum the social, environmental, and climate footprint throughout the value chain.[31]

VIII. ARTISANAL AND SMALL-SCALE MINING (ASM)

Although artisanal and small-scale mining (ASM) does not contribute significantly to production volume and operational efficiency, it plays an important role in providing livelihood opportunities. Globally, ASM employs about 42 million people and accounts for 20% of the global Gold supply, 80% of the global sapphire supply, and 20% of the global Diamond supply[32], although the quality of jobs and income is very low. 32% of the ASM global workforce resides in Africa, second after South East Asia (38%).[33] Women comprise about 40-50% of Africa's ASM workforce.[34] Therefore, ASM is an essential contributor to rural development.

[30] Anglo American, Future Smart Mining, 2021
[31] World Bank, Climate Smart Mining: Minerals for Climate Change, n.d.
[32] IISD. ASM Global Trends, 2018
[33] Pact World, Mapping Artisanal Small Scale Mining, 2018
[34] IISD. ASM Global Trends, 2018

Figure 7: Comparing LSM and ASM



Graph adopted from Haan, et al. (2018), Pact World.org, Mapping Artisanal and Small Scale Mining to the Sustainable Development Goals (NB: Graph not created to scale)

Like Large Scale Mining (LSM), ASM activities contribute to resource exploitation and environmental pollution. ASM's ecological impact is arguably worse than LSM because mining activities are mostly informal without monitoring and regulations.[35] The use of low technology, tools, and inadequate resource extraction and processing in ASM is inefficient, generating large volumes of waste and chemical pollution. ASM operators often recover a fraction of the targeted minerals in a given ore deposit – most ASM miners report using basic gravimetrical methods to recover no more than 30% of Gold.[36] Additionally, the use of chemicals such as mercury and cyanide, with limited guidance on safety and waste management, has dire impacts to the environment, such as water pollution - enhancing siltation and degrading aquatic habitat. Other impacts include land degradation, deforestation, and loss of biodiversity.

The circular economy is essential to ensure the sustainability of mining activities as well as the reliability of ASM as one of the pathways towards rural development. The ASM resource efficiency in mining is emerging as an international priority. International regulations are becoming stricter, and markets are becoming more conscious and concerned about sourcing raw materials from developing countries, fragile states, and critical ecosystems.[37] The circular economy offers a framework to improve the extraction of minerals and ensure minerals extracted from ASM meet the standards required by international stakeholders and preserve critical ecosystems. Not addressing such concerns could lead to a decrease in revenues from global markets, consequently affecting rural livelihoods.

[35] Life Gate, Artisanal Small Scale Mining in Africa, 2019
[36] Life Gate, Artisanal Small Scale Mining in Africa, 2019
[37] Pact World, Mapping Artisanal Small Scale Mining, 2018

ASM formalization is key to effective adaption of circular economy for ASM. ASM formalization serves as an immediate and urgent step for governments to undertake, given the rather disruptive nature of ASM activities. Formalization would allow governments to be able to monitor and regulate the sub-sector. In addition, formalization would allow ASM to access finance from formal institutions which can be used to invest in equipment needed for mining and to access geological data which would upgrade ASM mining activities and minimize environmental degradation, increase efficiency, improve profitability, and improve livelihoods.

Opportunities

There are numerous opportunities for ASM to enter the circular economy. ASM conduct their activities through small mining projects, and some scavenge and reprocess waste ores, including tailings. If empowered, ASM could play a significant role in recycling tailings and other waste materials at the mining sites. However, for this to be implemented effectively, formalization of the sector, improvement of technology, tools, and technical expertise must be invested to create ASMs that yield economic efficiency, improve livelihoods, and preserve the environment. Additionally, similar opportunities found in the LSM apply to ASM, such as using renewable energy to run machines, encouraging recycling of resources, particularly wastewater, and afforestation to rehabilitate the land. However, the transition requires a high capital investment that is currently missing in ASM.

IX. POLICY INTERVENTIONS

Research shows that improving the enabling environment, creating incentives, and formalizing ASM will be crucial for supporting the transition to a circular economy in the African mining industry.

Integrate CE in mining policies: Governments could integrate circular economy in mining policies and articulate the industry's roadmap towards circularity. The road map should be comprehensive, including stages and support the government is willing to offer the mining sector to transition towards CE. This could also mean revising current national regulations to promote circular opportunities discussed above or creating forums initiatives to help integrate CE in the mining industry. For example, creating mining transparency initiatives that trace mining value and supply chains will be essential in monitoring and enforcing the mining sector's transition towards circularity. Transparency initiatives are critical in material traceability, necessary for circularity, particularly in reusing and recycling as well and accountability.

Create regulatory and monetary incentives: Governments could create policies that hold mining industries responsible for the environment, such as Extended Producer Responsibility (EPR). EPR will be an incentive to minimize resource consumption, waste generation, promote more environmentally conscious processes during mining, and support public-sector management of waste. Monetary policies could be clean technology tax exemptions or subsidies for recycling and reduce the use of virgin materials. Governments can also provide macroeconomic support to industries and businesses that aim to shift to the circular economy model, such as investing in infrastructure supporting CE such as renewable energy. Monetary support is essential as mining firms claim cost being an issue to moving towards circularity. Thus, creative economic policies could encourage the move towards circularity and innovation.

Formalizing ASM is necessary to ensure the transition of ASM towards circularity. Formalizing ASM will help regulate and monitor mining activities and increase the economic, social, and positive environmental impact of ASM. Formalization will also help incorporate circular economy principles provide a pathway that could facilitate circular economy investments. Formalization of the mining sector will illuminate ASM's contribution to rural development, as well as its contribution to GDP and government revenue through taxation and export earnings. Additionally, women constitute most of the ASM workforce; thus, formalizing and creating comprehensive policy frameworks will help move the industry towards circularity as well as improve gender equality in the industry.

X. ANNEX

Figure 1: Minerals are the most consumed materials in the world (bn tons p.a.)[38]

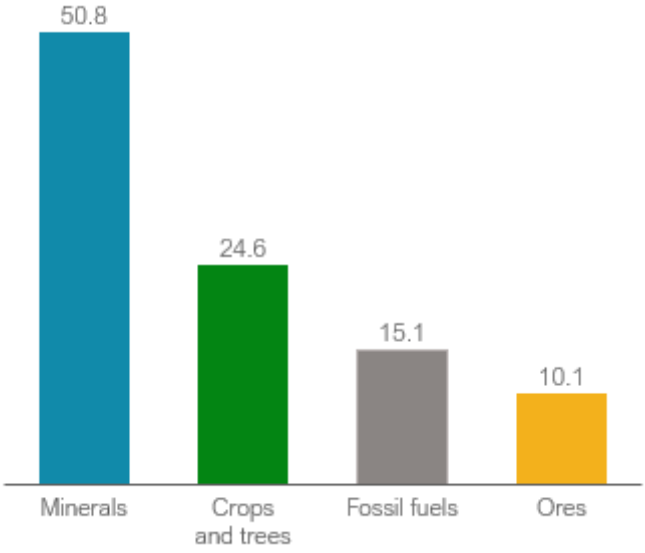
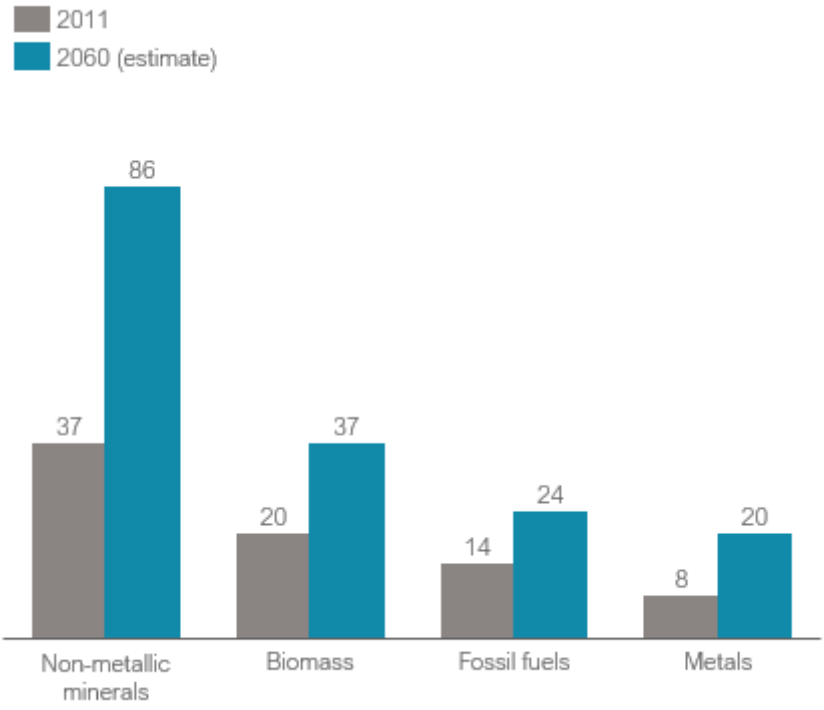


Figure 2: Global material use (2011 total = 79 gigatons, 2060 total = 167 gigatons)[39]



[38] The Guardian, World's Consumption of Materials, 2020
[39] OECD, Global Material Resources Outlook 2060, 2019

Figure 3: The world wastes about 33% of materials used each year (bn, tons)[40]

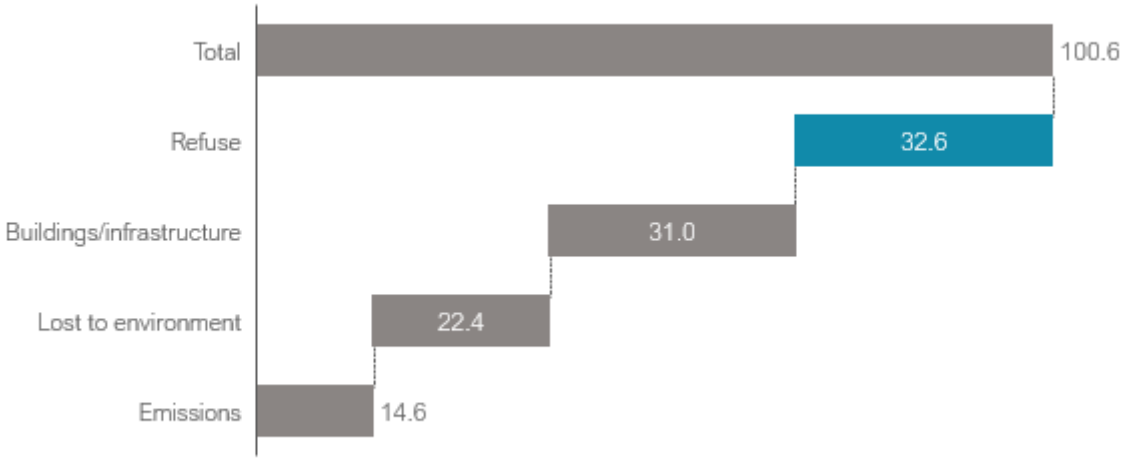


Figure 4: Africa Mineral Reserves[41,42]

[40] The Guardian, World's Consumption of Materials, 2020
[41] Mining in Africa, Mining in Africa, 2017
[42] UNEP, Our Work in Africa, 2021

Figure 5: Value of select mineral exports in Africa in 2018 (USD bn)[43]

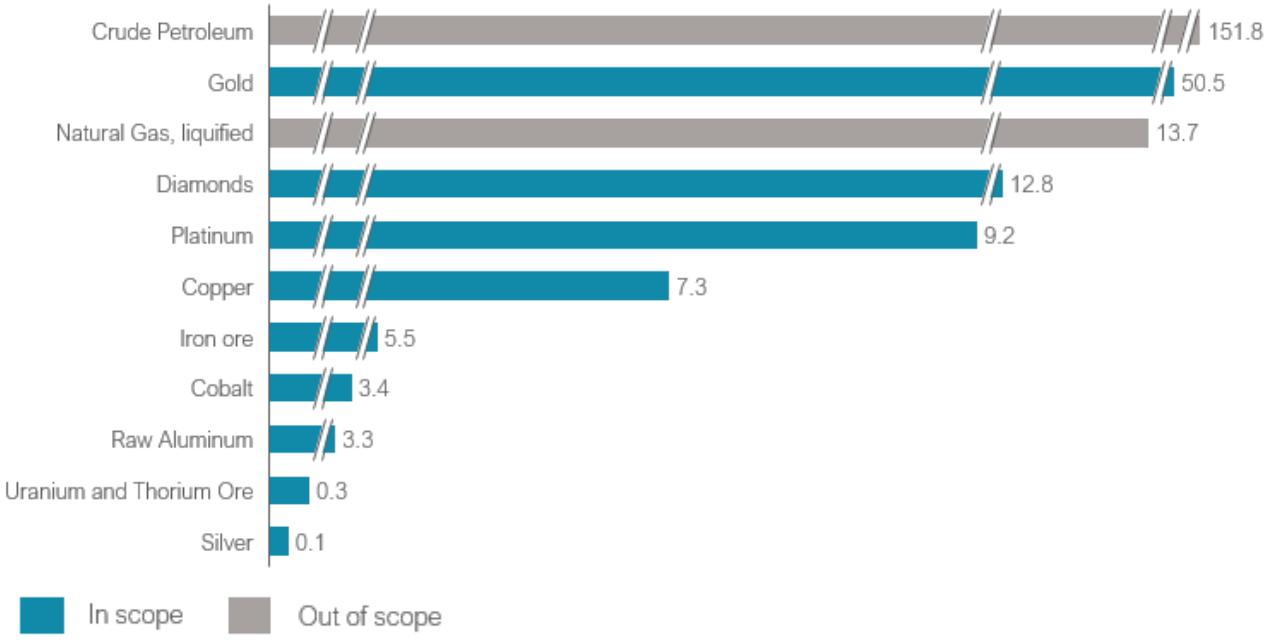


Figure 6: Copper Content Production in Africa 2018 (thousands of short tons)[44]

[43] The Observatory of Economic Complexity, Profiles, n.d
[44] Annual Data, Copper Supply & Consumption, 2020

Figure 7: Top Gold producing countries in Africa 2019 (tons)[45]

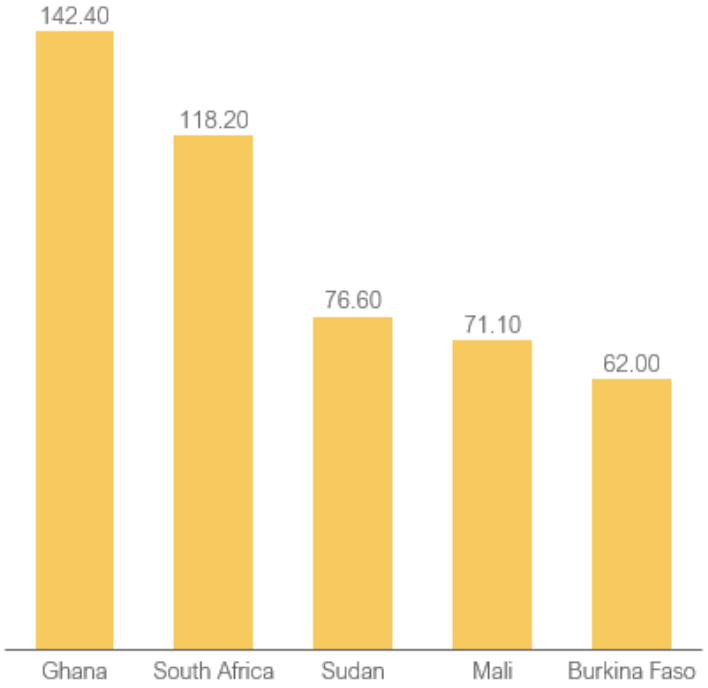
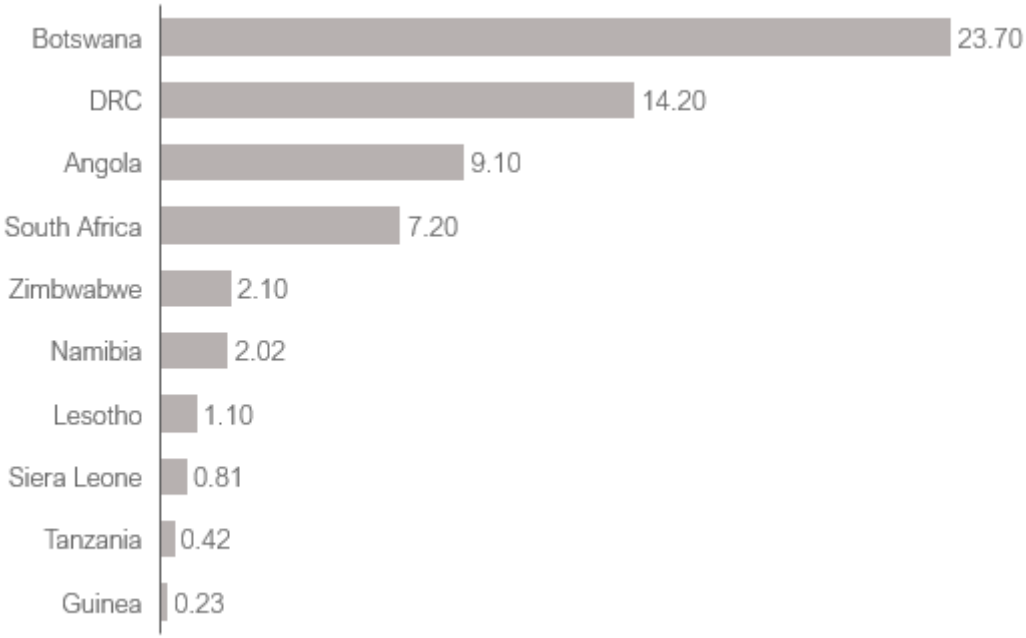


Figure 8: Top Diamond producing countries in Africa in 2019 (million carats)[46]



[45] NS Energy, Top five gold mining countries of Africa from Ghana to Burkina Faso, 2020
[46] Kimberley Process Statistics, Annual Global Summary: 2019 Production, Imports, Exports, and KPC Counts, 2020

Figure 9: Potential emissions reduction and transition pathways for Gold[47]

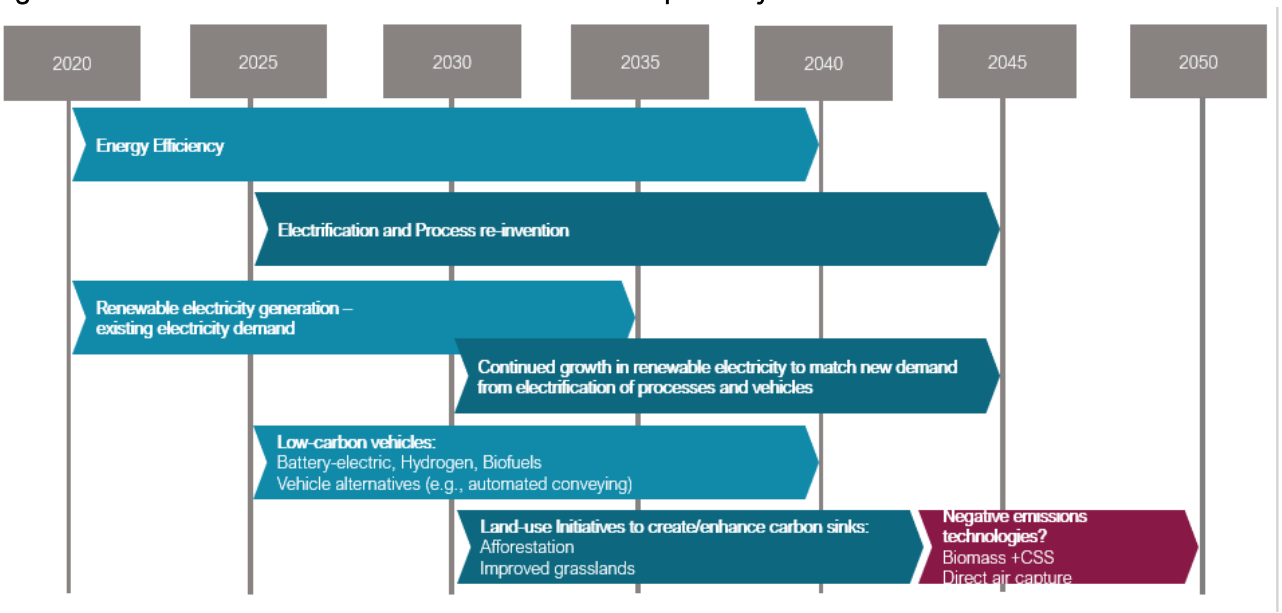
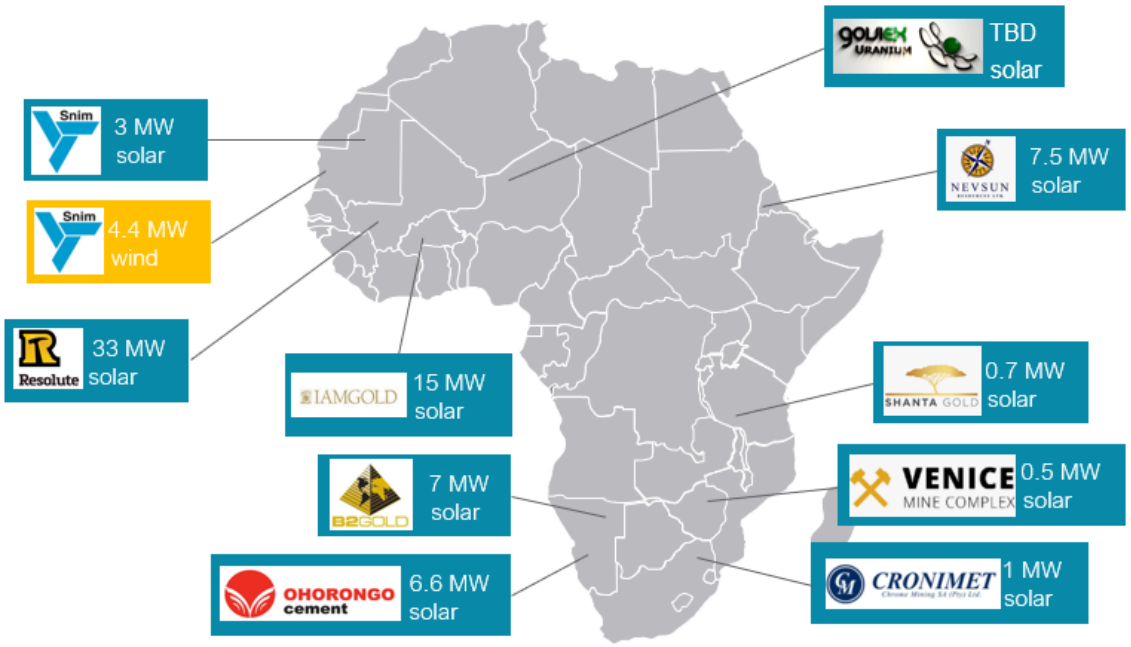


Figure 10: Major on-site renewable energy systems for mining operations in Africa[48]



[47] World Gold Council, Gold and climate change: The energy transition, 2020
[48] Daniel Gleeson, Renewable energy use can bring savings to Africa mining sector, report claims, 2019

Figure 11: Global smartphone market share in 2019 (%)[49]

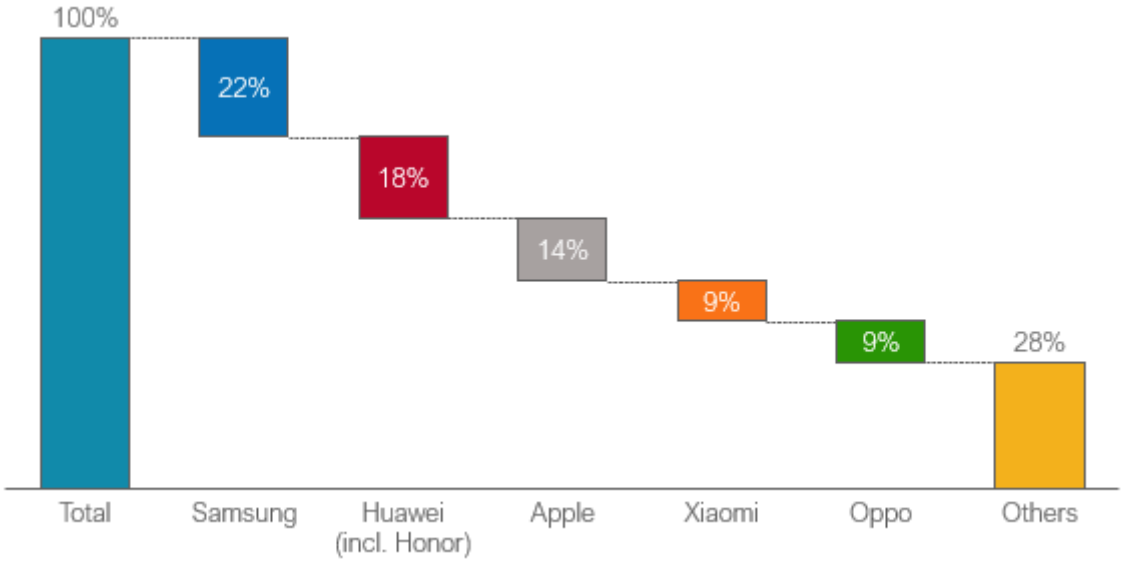


Figure 12: ASM workforce by region.[50]

[49] Canalysis, Worldwide smartphone shipments Q4 2020 and full year 2020, 2021
[50] Pact World. Mapping Artisanal Small Scale Mining, 2018

Table 1: Summary of opportunities and their feasibility and impact score

Circular Economy Principle	Opportunity	Impact			Feasibility		
		Reduce emissions or waste	Reduce consumption of virgin materials	Create jobs	Low cost of implementation	Already undertaken (momentum)	Accessibility of resources
Recycle/ reduce/ reuse resources and waste	Recycle wastewater	0.8	0	0.8	0.6	1	0.8
	Recycle and reuse vehicle parts	0.6	0.8	0.8	0.6	1	1
	Recycle tailings and repurpose waste rock	1	1	0	0.5	1	1
	Recycle and reuse construction materials	1	0.5	1	0.8	1	1
	Rehabilitation of mines	0.8	0	1	0	1	0.5
	Merge CSR strategies and CE	1	0.5	0.8	0.6	0	1
	Recycle food waste for energy generation	1	0	0	1	1	1
Regenerate natural resource	Renewable energy	1	0.8	1	0	1	0.8
	Reduce energy consumption	0.8	1	0.8	0	1	0
Design out waste	FutureSmart™ Mining	1	1	1	0	0	0

Table 2: List of interviewed experts

Name	Position	Organization	Former organization(s)	Mining category
Arif Moreno	Strategic Advisor to CEO	Anglo American	PwC	Policy
Ayodele Bolaji	Production Engineer	Addax Petroleum	Famfa Oil Ltd. Amazon Energy Ltd.	Extractives
Charlene Wrigley	Group Sustainable Development Manager	Gold Fields Ltd.	AngloGold Ashanti, Katanga Mining Company, WSP Environment & Energy	Sustainability
Gwakisa Mwakyusa	COO	Tansheq Limited	De Beers – Williamson Diamonds Limited	Mineral Processing
Jan Klawitter	Head of International Policy	Anglo American	WEF	Policy
Nicholas Kumalinga	Independent Consultant	Nitrade Consulting	Anglo American, AngloGold Ashanti, Jubilee Metals Group PLC, Mining One Consultants, DTE Project Management (Pty) Ltd	Metallurgy
Noleen Dube	Head of Corporate Affairs Africa	South32	Acacia Mining PLC, AngloGold Ashanti, IFC	Sustainability
Patrick Nanyaro	CFO	DSM Corridor Group Co. Ltd.	Acacia Mining PLC, Shanta Mining Co. Ltd, Mantrac Tanzania Limited	Finance in mining

Table 3: Opportunities in mineral distribution[51]

Opportunity	Description
Urban Mining	Post-consumption waste has been categorized as electronic waste (i.e., minerals, spare parts, scrap metal, etc.) and non-electronic waste (i.e., minerals that are not used in electronics, e.g., gypsum). Recycling post-consumption waste was coined "urban mining," and companies like Urban Mining Company recycle rare earth metals to produce magnets, which saves 11 tons of CO_2 per ton of magnet produced relative to magnets using virgin materials.
Mineral traceability	Follows the trail of minerals along the supply chain by monitoring and tracking chain of custody. Traceability is becoming increasingly useful for downstream electronics/automotive manufacturing companies like Apple are increasingly demanding information on the metals and mineral used in their products.
Owning the value chain	Involves countries not only selling but also leasing minerals for a period of time.

[51] Colin Staub, Rare earth recycler draws $28 million in federal funding, 20