



## GREEN MINING FOR SUSTAINABLE MINING IN NIGERIA

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### ABSTRACT

*Green mining refers to technologies, best practices and processes that reduce environmental impacts while ensuring efficient mineral resource extraction. Mining operations always impact negatively the natural environment, economy and social structure of the area where mineral extraction takes place. The goal of green mining, therefore, is to minimise the adverse environmental and social impacts in all stages of the operations. Nigeria, endowed with significant mineral resources, faces significant environmental degradation due to traditional mining practices over the decades. Green mining technology offers a sustainable alternative, enabling environmentally responsible mineral extraction while promoting economic development. It is believed that Nigeria's mineral sector holds tremendous potential to diversify the national economy beyond oil dependence. However, mining practices, particularly in artisanal and small-scale operations, contribute heavily to land degradation, water pollution and deforestation. To align with global sustainable development goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), Nigeria must transition to green mining practices. This paper explores the application of green mining technologies in Nigeria, assesses current practices, evaluates environmental and socio-economic impacts and proposes strategies for implementation. Key technologies such as bioremediation, water treatment, renewable energy use and automated monitoring systems are examined in the Nigerian context.*

### 1.0 INTRODUCTION

As the world begins to demand greater environmental accountability, mining operations in many countries around world are implementing technologies that reduce the environmental footprint throughout the lifecycle of the mining enterprise. Green mining, also known as environmentally sustainable mining, aims to reduce the environmental footprint and promote responsible resource extraction. The environment is not just a backdrop to economic activity; it's the foundation of life itself encompassing land, water and air – basic supporting ingredients of life. Rivers provide water for agriculture; forests on land sustain biodiversity and clean air sustains life and keeps humans healthy.

Neglecting these resources for short-term gains is like removing the ladder after climbing up. Neglecting the environment therefore is shortsightedness and foolhardy.

Modern mining practices and technologies can minimize environmental damage while maximizing economic benefits at the same time. On one side lies the promise of boundless economic growth, driven by its vast mineral resources; on the other hand, there is a pressing need to protect our environment from irreversible damage which can result from irresponsible mining activities. However, with the right strategies, Nigeria can harmonise economic advancement with environmental preservation by adopting green mining practices—a true win-win scenario that benefits both the present and future generations.

## **2. HISTORICAL BACKGROUND ON USE OF ENERGY**

Nearly all energy used before the 19<sup>th</sup> century, was renewable. The oldest known use of renewable energy, in the form of traditional biomass to fuel fires, dates from more than a million years ago. The use of biomass for fire did not become commonplace until many hundreds of thousands of years later (Kris, 2013). Probably the second oldest usage of renewable energy is harnessing the wind in order to drive ships over water. This practice can be traced back some 7000 years, to ships in the Persian Gulf and on the Nile. From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times (Geothermal Energy, 2017). Moving into the time of recorded history, the primary sources of traditional renewable energy were human labour, animal power, water power, wind in grain crushing windmills and firewood a traditional biomass. In the 1970s environmentalists promoted the development of renewable energy both as a replacement for the eventual depletion of oil, as well as for an escape from dependence on oil and the first electricity-generating wind turbines appeared.

## **3. ROLE OF GREEN MINING IN ADDRESSING CLIMATE CHANGE**

The terms “green” and “mining” haven’t traditionally sat comfortably together but things are starting to change. As a developing country, robust mining can provide revenues to fund critical infrastructure, create millions of jobs and boost GDP growth. But these benefits from mining must not come at the expense of our land, water and air. If we destroy the environment in pursuit of wealth or development, we lose far more than we gain. As we progress through the 21<sup>st</sup> century, the importance of green energy in shaping our modern world cannot be overstated. Many countries and mining companies have acknowledged the challenge and have stated their commitment to the values of sustainability. Nigeria should do the same because Nigeria is not immune from the negative impact of mining on the environment, especially emission of greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O etc.).

## **4. OVERVIEW OF ENVIRONMENTAL IMPACTS OF TRADITIONAL MINING IN NIGERIA**

Traditional mining practices have long been associated with significant environmental impacts in Nigeria, including: Blasting and excavation, resulting in land disturbance and ground vibration; Habitat destruction and deforestation; Land degradation and Soil erosion; Air and water pollution; Waste generation and the release of chemicals and heavy metals into the environment. Some of mining activities that have caused pollution are discussed below:

### **4.1 Sedimentation and Erosion**

Mining that involves removing overburden and scraping away rocks to get the mineral buried near the surface, leads to the destruction of agricultural lands and erosion of soil. Plants, trees and topsoil are scraped away from the mining area and destroy wildlife habitats and landscapes. When these mining

sites experience heavy rain, the loosened topsoil is washed away, carrying sediments that may pollute the streams, lakes and rivers. Excessive residue can harm aquatic organisms and watershed vegetation downstream. Moreover, it can also cause disfiguration of streams and river channels, which results in flooding.

#### **4.2 Water Pollution**

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. The mining and processing of mined materials generally require water. Water is also the primary vehicle by which mining-related contaminants can inadvertently be transported into the environment and worsen the quality of water resources. Mining water pollution has severe consequences for wildlife and human life. Protecting endangered species and maintaining clean water sources are crucial for sustaining biodiversity, ensuring human health and well-being. Prevention of water quality degradation is an important step in ensuring environmental sustainability in mining areas.



**Figure 1.** Polluted section of the Osun river from artisanal gold mining activities, Osogbo (Source: Eromo Egbejule and Festus Iyorah. Published On 2 Sep 2022)

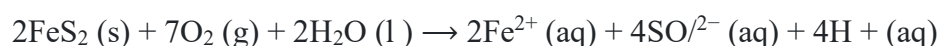


**Figure 2.** Polluted water bodies at mining sites, near Abakaliki, Ebonyi state. (Source: SOFRECO/Beak consultants, MMSD, 2019)

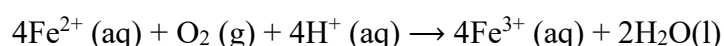
### 4.3 Acid Mine Drainage

Acidic discharges from active or abandoned mines are called *acid mine drainage* (AMD) or acid rock drainage (ARD). Acid mine drainage is the formation and movement of highly acidic water rich in heavy metals. This acidic water forms through the chemical reaction of water with rocks that contain sulphur-bearing minerals, resulting in sulphuric acid. The pH of AMD is usually in the range of 2–6. Some or all of this iron can precipitate to form the red, orange, or yellow sediments in the bottom of streams.

- (i) *Acid Mine Drainage (AMD)*: When sulphide-containing rocks are exposed to air and water, they can react to form sulphuric acid, which can leach into groundwater and surface water, polluting it with heavy metals and acid.
- (ii) *Chemistry of AMD*: Although a host of chemical processes contribute to acid mine drainage, pyrite oxidation is by far the greatest contributor. A general equation for this process is:



The oxidation of the sulphide to sulphate solubilizes the ferrous iron (iron(II)), which is subsequently oxidized to ferric iron (iron(III)):



Either of these reactions can occur spontaneously or can be catalyzed by microorganisms that derive energy from the oxidation reaction. The ferric cations produced can also oxidize additional pyrite and reduce into ferrous ions. The net effect of these reactions is to release  $\text{H}^+$ , which lowers the pH and maintains the solubility of the ferric ion.

- a) *Heavy Metal Contamination*: Mining operations release heavy metals like arsenic, lead, mercury and zinc into the environment, which can contaminate water sources and leach into the soil.
- b) *Tailings and Waste Rock*: Mining processes generate vast amounts of waste, including tailings (material left over after ore processing) and waste rock. These materials can contain toxic substances and heavy metals that can leach into soil and groundwater.
- c) *Processing chemicals pollution*: Mining companies generally use chemical compounds such as sulphuric acid or cyanide to separate their respective target minerals from the ore. Contamination occurs when these chemicals are leached, leaked, or spilled from the mining area into the nearby bodies of water; contaminating water sources and harming aquatic life. These chemicals are highly toxic and could lead to loss of life on wildlife species and severe health concerns on the human body.



**Figure 3.** Left: River pollution by acid mine drainage. Right: Polluted river after cleaning

An analysis of water quality in Onyema and Okpala mine districts in Enugu, Southeast, Nigeria was reported by mean values of heavy metals namely; Cadmium, Arsenic, Lead, Chromium were respectively reported as 0.33mg/l, 0.06 mg/l, 0.53mg/l and 0.06 mg/l with mean pH values of 5.4 all of which exceeded the WHO permissible limits of 0.0-5.0mg/l for all the metals identified.. It was also reported that total dissolved solids (TDS) values ranging between 21.80 and 520 mg/l were below WHO permissible limits of 0.00-1500 mg/l but however injurious to the aquatic life in the catchment (Ojonimi, 2020).



Figure 4: Reprocessing of gold using cyanide at Uke gold mining site (Source: SOFRECO/Beak consultants, MMSD, 2019)

#### **4.4 Air Pollution**

Air pollution from mining activities is a significant concern, affecting both the environment and human health. Mining releases particulate matter (PM), gases, and toxic metals into the air, contributing to respiratory problems, cardiovascular diseases, and other health issues for workers and nearby communities

- (i) *Dust and Particulate Matters*: Mining activities, such as blasting, hauling and smelting, generate dust and particulate matters that can be released into the atmosphere, impacting air quality and potentially affecting human health.
- (ii) *Gases*: Blasting operations release gases like carbon dioxide, nitrogen oxides, and sulfur dioxide into the atmosphere.
- (iii) *Smelting Emissions*: Smelting, the process of extracting metals from ore, releases toxins like lead, mercury and sulphur dioxide into the atmosphere.

#### **4.5 Soil Pollution**

Soil pollution from mining activities is a significant environmental concern, affecting ecosystems, human health and food security. Mining releases toxic metals, chemicals and waste, contaminating soil and posing long-term risks.

- a. *Heavy Metal Contamination*: Mining activities can contaminate soil with heavy metals, making it unsuitable for agriculture and impacting plant and animal life.
- b. *Tailings and Waste Rock*: Tailings and waste rock can be deposited on land, contaminating the soil with toxic substances and heavy metals.



Figure 5: Primary processing of gold at Uke mining site, Nasarawa state  
(Source: SOFRECO/Beak consultants, MMSD, 2019)

#### 4.6 Habitat Destruction and Biodiversity Loss

Habitat destruction and biodiversity loss are significant environmental concerns associated with mining activities. Mining can lead to deforestation, habitat fragmentation, and loss of ecosystems, threatening species and ecosystems.

*Deforestation:* Mining operations often require clearing large areas of land, leading to deforestation and habitat destruction.

#### 4.7 Fire-setting

Fire-setting is a method of traditional mining used most commonly from prehistoric times up to the Middle Ages. Fires were set against a rock face to heat the rock, which was then doused with water or any other kind of liquid, causing the rock to fracture by thermal shock. In some places where some communities are nearby, fire setting is still used to avoid consequences of use of explosives. A good example is fire-setting activities at Magnet quarry, Kaduna (Figure 4:6)



Figure 6. Fire-setting activities at Magnet quarry, Kaduna  
(Source: Lawal, 2024)

Although fire-setting was frequently used before modern times, it has been used sporadically since then. The artisanal miners set fire on the rock mass to weaken its strength. Water is then sprayed on the rock to cool it. The effect of heating and cooling (expansion and contraction) leads to cracking of

the rockmass. The already weakened rockmass is then broken into smaller pieces using hammer and chisel. This practice is common in some areas in the country especially where big operators have ceased working or places where blasting operations cannot be carried out. Example Malali in Kaduna

#### 4.8 Waste from mining process

An ore is a mineralized rock containing valued metal(s) such as gold or copper. Mining involves the excavation of large quantities of waste rock in order to extract the desired mineral. The ore is then crushed into finely ground particles for separation of valuable minerals from non-valuable components that are discarded as tailings or waste. Similar wastes are also generated from other minerals other than ores, for instance coal resources, non-metallic or industrial minerals.

### 5. TRANSITION TO SUSTAINABLE DEVELOPMENT

Nigeria is a signatory to many of the protocols or agreements on globalization, social and environmental concerns. Green energy is important for the environment because it can replace the negative effects of fossil fuels (emission of greenhouse gases e.g. CO<sub>2</sub>, CH<sub>4</sub>. Clean energy are those types which do not release pollutants into the air and renewable energy comes from sources that are constantly being replenished, such as hydropower, wind power or solar energy. Sustainable development is progress and transformation that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is critical that no one is left behind. The transition to sustainable development is primarily grounded in a series of international agreements and goals that are then implemented at the level of the individual states and communities involved. Among these, the best known are: The *United Nations Framework Convention on Climate Change* and its protocols, which set commitments to reduce greenhouse gas (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O etc.) emissions;

1. The *Convention on Biological Diversity (CBD)*, which promotes the conservation of biodiversity; and,
2. More importantly, the UN Sustainable Development Goals (SDGs), which cover a wide range of sustainability issues. Built around these goals is the UN 2030 Agenda, a plan of action for people, planet and prosperity, signed into law by the UN General Assembly on September 25, 2015. The Agenda includes 17 goals, valid for everyone around the world, articulated along the three dimensions of sustainable development: economic, social and environmental.



Figure 7. Sustainable Development Goals (SDG, 2015)

### 6. ENERGY TRANSITION PLAN FOR NIGERIA

Energy transition refers to the global energy sector's shift from fossil-based systems of energy production and consumption — including oil, natural gas and coal — to renewable energy sources. In 2021, Nigeria's Energy Transition Plan (ETP) was created with COP26 support, prompting Nigeria's

net-zero commitment by 2060. The plan has government approval and presents a \$23 billion opportunity for supporting financiers and partners. The plan maps a pathway to reduce Nigeria's dependence on hydrocarbon sources, emphasizing renewable energy. The plan aims for net-zero emissions by 2060 and proposes gas commercialization until 2030, then a gradual fossil fuel phase-out. The plan aims to reduce Nigeria's greenhouse gas emissions and improve air quality. It estimates that the transition could reduce Nigeria's greenhouse gas emissions by up to 45% by 2030 and up to 90% by 2050. The plan is expected to create significant economic opportunities and job creation across various sectors of the economy, including renewable energy, energy efficiency and electric vehicles. This is a possibility that 5 million new jobs could be created by 2030. Estimates are that US\$1.9 trillion will be invested in the sector by a full transition in 2060. This includes initiatives to support developing sectors like electric mobility, green hydrogen and capacity-building for the creation of new markets. There is a need for policy and regulatory change mainly aimed at creating a conducive environment for businesses to invest in energy transition. There is also a need for significant capacity building and skill development to support roll-out and growth of new technologies.

## **7. DEVELOPMENT OF NIGERIA'S MINERAL RESOURCES**

Nigeria is blessed with abundant mineral resources including:

- |  |  |
|--|--|
| a. Precious metals (Gold, Silver etc.),  | s. Green Energy Minerals/Metals          |
| b. Metallic Minerals (Cassiterite, Tantalite,  | (Lithium, Tin, Cobalt, Nickel, Graphite, |
| c. Iron ores, Columbite, Lead/Zinc Sulphides,  | t. Copper,                               |
| d. Chromite,   | u. Aluminium,                            |
| e. Copper ores,  | v. Manganese,                            |
| f. Molybdenite,  | w. Neodymium,                            |
| g. Manganese, Wolframite,  | x. Zinc,                                 |
| h. Bismuthine etc.), Industrial Minerals & Dimension stones/Construction minerals (Clays, Barytes, | y. Rare Earth Elements                   |
| i. Gypsum, Feldspar, Limestone/Marble, Kaolin,   | z. etc.                                  |
| j. Talc,   |  |
| k. Mica,   |  |
| l. Diatomite,  |  |
| m. Sand,   |  |
| n. Phosphate,  |  |
| o. Soda ash,   |  |
| p. Granite   |  |
| q. Gemstones (Amethyst, Aquamarine, Tourmaline, Garnet, Zircon, Sapphire etc),                     |  |
| r. Fossil Fuels (Coal, Tar sands),   |  |

The *grundnorm*, that is, the fundamental rule or principle that underpins the Nigerian mining law and serves as the basis for all other laws in the development of minerals in the country is the Nigerian Minerals and Mining Act (NMMA), 2007. The NMMA is the most important law on which all other laws, such as, the *Regulations*, policies are based.

## 8.0 Green Mining Technologies

The concept of “green mining” is no longer a futuristic fantasy—it’s happening worldwide. From renewable energy-powered operations to advanced waste recycling systems, mining companies have access to a suite of eco-friendly tools. One of the core principles of green mining is the transition to renewable energy sources for mining operations. Instead of relying on fossil fuels, which contribute to climate change, green mines are adopting solar, wind and hydropower technologies to power their operations. In general, mining techniques have become much more environmentally sensitive when efficiency is improved because less waste is produced.

Green mining techniques include in situ leaching and bio-mining, which reduce surface disruption and energy use. Other key practices involve integrating renewable energy, using energy-efficient and electric/hybrid equipment, and improving water and waste management through methods like closed-loop recycling and waste reuse. Advanced technologies such as digitalization, automation, and carbon capture also contribute to sustainability.

- a) *In-situ mining and bioleaching*: Green mining embraces innovative techniques, like *in-situ* recovery and bioleaching, which minimize surface disruption and reduce environmental footprint. These methods are particularly useful for extracting minerals from ore bodies that are hard to access through traditional means.
- b) *Bioremediation*: Use of microorganisms to detoxify polluted soils and water in mining areas. This can be applied post-mining to restore ecosystems affected by heavy metals.
- c) *Use of electric vehicles*: The use of advanced equipment, such as electric vehicles and energy-efficient machinery. The deployment of electric haul trucks and processing units is a key component of green mining technology, offering a practical solution for reducing greenhouse gas emissions associated with mineral extraction and processing. Traditional diesel-powered mining machinery contributes significantly to CO<sub>2</sub> emissions, air pollution, and operational costs. Replacing these with electric-powered alternatives enhances environmental sustainability and improves operational efficiency.
- d) Renewable energy sources like solar and wind power are also being integrated into mining operations to reduce reliance on fossil fuels. In addition, solar and wind power have the advantage is that electric mining equipment can be powered by renewable energy, especially solar. Nigeria’s abundant solar radiation makes it ideal for charging battery-electric mining vehicles. These renewable energy sources can also power processing machinery at artisanal mining sites by creating mini-grids to support mining clusters with clean and stable electricity. This integration would significantly reduce the use of diesel, which is both expensive and environmentally harmful. These will align with Nigeria’s Energy Transition Plan (ETP) aiming for net-zero emissions by 2060.

## 9. CHALLENGES TO IMPLEMENTATION

Despite the advantages, several barriers must be addressed:

*High Capital Costs*: Importing electric mining equipment can be cost-prohibitive for small and medium mining enterprises.

*Infrastructure Deficiency*: Lack of charging infrastructure, spare parts, and trained technicians limits large-scale adoption.

*Policy Gaps:* There is currently no national incentive for mining firms to adopt electric equipment or switch to renewable energy.

*Resistance to Change:* Many operators are unfamiliar with the benefits or technical requirements of electrification.

### **9.1. Water Management, Conservation and Treatment**

Green mining emphasizes water conservation and efficient management practices. Mining operations can significantly impact local water resources, leading to water scarcity and pollution. Mines can implement strategies to minimize water consumption by recycling and reusing water wherever possible. Furthermore, advanced water treatment technologies are being employed to ensure that any discharged water is clean and safe for the environment.

### **9.2. Sustainable Materials Handling**

Efficient materials handling is essential for minimizing waste and reducing the environmental impact of mining. Innovations help increase resource recovery rates. For example, bulk ore sorting separates valuable minerals from waste early in the process.

### **9.3. Selective Mining and *in-situ* mining**

Selective mining involves extracting only high-grade materials, leaving lower-grade ores in place. This approach reduces waste generation and decreases the amount of material that needs to be processed, minimizing the overall environmental impact. Therefore, do selective mining first and follow it by doing *in-situ* mining

**9.4. Ecosystem Restoration:** Traditional mining often leads to the destruction of natural habitats and biodiversity loss. Green mining seeks to restore ecosystems impacted by mining activities. After the closure of mining operations, reclamation efforts are undertaken to rehabilitate the land and support the return of native flora and fauna.

*Reprocessing of tailings:* Sometimes amounts of the metals being mined end up in the wastes. Reprocessing these wastes can result in more usable material.

*Dust suppression techniques:* During the mining process, large amounts of dust are released into the atmosphere. This can be minimized by pre-wetting the areas to be blasted with high volume sprinklers. Dust in the air, can also be removed through mist cannons (very high-volume water sprinklers).

*Liquid membrane emulsion technology:* This is a separation technique that can be used to extract usable metal from highly toxic or acidic waste water produced by a mine. This technology can even deal with dilute solutions

*Choice of ventilation system and diesel engines:* 10 percent of mining costs come from electricity consumption. Better ventilation systems and diesel engines can maximize efficiency in mining operations.

### **9.5 Community Engagement and Social Responsibility**

Green Mining recognizes the importance of engaging with local communities and respecting their rights. It involves the creation of sustainable livelihoods, fostering economic opportunities, and investing in social development projects. This approach not only improves the quality of life for nearby

communities but also ensures the long-term success of the mining operation by gaining community support.

## **10. CHARGING TOWARDS THE FUTURE**

The green mining technology is still in the early stages, with many of these technologies still in concept stages and as with most emerging technologies, the only foreseeable way that large-scale transition can occur will require government incentives and a potentially a move towards a price on carbon and/or other pollutants. The path to a better tomorrow is rarely easy, but Nigeria has what it takes to walk it. By prioritizing both economic growth and environmental preservation, we can secure a legacy of prosperity and sustainability for future generations. The time to act is now. Let's build a future where Nigeria's mining industry sets the gold standard for the world.

Green mining can offer many benefits in the exploitation of Nigeria's mineral resources. These include:

- a) *Environmental Conservation*: Green mining practices minimize the negative environmental impacts of mining, such as deforestation, water pollution, and soil degradation. This is achieved through sustainable mining technologies, reclamation strategies, and waste management techniques.
- b) *Job Creation and Economic Growth*: The mining industry provides employment opportunities and stimulates local economies, contributing to economic growth and development. Green mining can ensure that these benefits are sustained while minimizing harm to the environment.
- c) *Improved Community Engagement*: Green mining encourages mining companies to engage with local communities, ensuring they benefit from mining activities through job creation, infrastructure development and social programmes.
- d) *Reduced Carbon Footprint*: The adoption of green technologies, such as solar and wind energy, can significantly reduce the carbon footprint of mining operations. For example, the Gold Fields Tarkwa Mine in Ghana has installed a 40 MW solar power plant to reduce dependence on fossil fuels.
- e) *Increased Investment Attraction*: African countries are attracting investments in green mining initiatives, local empowerment and environmental protection. The World Bank's Africa Mining Project has invested over \$300 million to support sustainable mining practices (Future of Mining, 2025).
- f) *Water Conservation*: Green mining practices prioritize water conservation and efficient use, reducing the risk of water contamination and ensuring that local communities have access to clean water.
- g) *Land Rehabilitation*: Mining companies are encouraged to restore land to its original state or repurpose it for sustainable uses after mineral extraction. This includes replanting trees, rebuilding topsoil and ensuring that water resources are clean and available for local communities. Overall, green mining offers a more sustainable and responsible approach to mineral exploitation, balancing economic benefits with environmental and social responsibility.

## **11. CHALLENGES AND OPPORTUNITIES**

Green mining in Nigeria faces challenges like a lack of funding, inadequate infrastructure, complex regulations, and security risks, but also presents opportunities for attracting investment, improving the environment, and fostering sustainable development. Overcoming these obstacles requires addressing the regulatory, financial, and security issues while capitalizing on the potential for eco-friendly innovation and investor incentives.

- a) *Regulatory Frameworks*: Strengthening regulatory frameworks can encourage the adoption of green mining technologies.
- b) *Research and Development*: Investing in R&D can help develop context-specific green mining technologies for Nigeria's mining industry.
- c) *Training and Capacity Building*: Providing training and capacity-building programs can enhance the skills of mining professionals in green mining technologies.

## 12. CONCLUSION

To ensure that Nigeria's mining sector remains a driver of economic growth without compromising environmental sustainability, there is a need for continued investment in green mining technologies and practices. Nigeria must collaborate with global partners, share knowledge and build capacity to develop a sustainable mining sector that contributes to both the green energy transition and the country's development goals.

Ultimately, the path to sustainable mining in Nigeria lies in the careful balance between harnessing the country's mineral wealth and protecting the environment. Through innovative solutions, regulatory reforms and increased community involvement, the giant of Africa can lead the way in sustainable mining for the green energy future. By prioritising environmental protection and sustainable practices, Nigeria can ensure that its mineral resources benefit not only the global green energy transition but also its own communities for generations to come.

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## Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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