

Environmental Monitoring and Recommendations for Reducing the Ecological Footprint of Alumina Production in Guinea

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Abstract

Guinea holds more than 25% of the world's bauxite reserves and aims to become a leader in local alumina processing. However, this industrial sector generates major environmental impacts: atmospheric emissions, alkaline liquid discharges, and massive production of bauxite residue (red mud). This article presents an analysis of the current environmental monitoring system for alumina refineries in Guinea, identifies the main environmental issues, and proposes recommendations for reducing the environmental footprint of this strategic sector. The results show that, despite the existence of regulatory frameworks, enforcement remains insufficient and environmental risks remain high. Technical, institutional, and socioeconomic measures are proposed to improve the sustainability of the sector.

Keywords

Alumina, Bauxite, Guinea, Ecological Footprint, Production, Environmental Monitoring, Sustainability

1. Introduction

The water tower of West Africa, described by some as a “geological scandal,” the Republic of Guinea possesses significant natural resources in terms of quantity, quality, and variety. In addition to a coastline stretching over 300 kilometers and rich hydrological potential, Guinea boasts a diverse mineral resource base: the country has the world's largest bauxite reserves (between 25% and 40% of the world's stock according to available estimates), making it the second-largest producer after Australia.

Guinea also possesses significant reserves of iron (notably the Simandou deposit, the world's largest iron ore reserve), gold, diamonds, nickel, and other metals (copper, lead, zinc, cobalt, manganese, nickel, black sand). More generally, the mining sector generates, on average, between 60% and 80% of export revenues and contributes a quarter of government revenues.

The extractive industries sector therefore constitutes an economic sector that is both structuring and strategic for the country in terms of development at the national and local levels, as well as in terms of access to basic services. However, the governance of the sector raises questions insofar as mining activities, whether industrial or artisanal, contribute to environmental degradation and make access to basic natural resources (water, land, fauna, and flora) more difficult. Mining activities can potentially weaken community coexistence between communities adopting different lifestyles (sedentary agriculture and transhumant livestock rearing) and highlight the intrinsic link between mining and the right of access to land usufruct and land ownership. In this context, access to mineral resources and their exploitation remain a source of regular disputes between local populations and foreign companies and their local operating companies, despite the existence of a revised legal framework at the national level [1].

This study analyses the environmental impacts of alumina production and proposes strategies to reduce its ecological footprint on ecosystems in the Boké region.

2. Materials and Working Methods

2.1. Presentation of the Study Area

The Republic of Guinea is a West African country endowed with exceptional natural resources and significant economic potential. Covering an area of 245,857 km², it is divided into several natural regions with distinct climatic, agricultural, and mining characteristics, such as Lower Guinea, Middle Guinea, Upper Guinea, and Forest Guinea.

Its population, estimated at approximately 14.4 million in 2023, is ethnically, linguistically, and religiously diverse. French is the official language, but numerous national languages, such as Fulani, Malinke, and Susu, are commonly spoken. The country has a predominantly Muslim population (85%), with Christian and animist communities also present.

Guinea has many natural assets: a maritime coastline, significant hydrological and agricultural potential, borders shared with six countries, and a subsoil rich in minerals (bauxite: the world's largest reserve with 25% of the stock and the world's second largest producer, 4 billion tonnes of iron reserves, 700 tonnes of gold, and 30 to 40 million tonnes of carats of proven diamond reserves). However, its economy remains relatively undiversified and structurally vulnerable to exogenous shocks, particularly in raw materials.

1) The contribution of the primary sector to GDP is relatively modest (29% of GDP in 2021), but this is expected to increase, thanks in particular to the devel-

opment in 2022 of nearly 14 million hectares of arable land owned by the State;

2) The secondary sector (31% of GDP) is dominated by mining activities, which, along with bauxite, gold, and diamonds, represent 18% of the country's GDP;

3) The tertiary sector (40% of GDP) is driven by trade, transportation, telecommunications, real estate, and business services. Strengthening agricultural activity has thus become one of the government's priorities in order to reduce the country's dependence on mining.

After 4% in 2022, economic growth reached 5.7% in 2023, driven by the mining sector, which benefited from increased Indian and Chinese demand for bauxite and aluminum, and whose growth reached 9.4%. Growth in the non-mining sector, driven by agriculture, also improved in 2023, reaching 4.8%. However, despite emergency financing granted to Guinea following the explosion at the Conakry fuel depot, economic growth is expected to slow in 2024 to 4.1%. This growth would remain driven by the mining sector, which is expected to grow by 7.6% in 2024, thanks in particular to the completion of the Simandou mining mega-project. In the medium term, economic activity is expected to continue to accelerate (5% to 6% per year between 2025 and 2028), again thanks to the booming mining sector (+10% per year on average). Despite its strengths, Guinea's socioeconomic indicators remain weak. With a population of 14.4 million and a GDP of USD 23 billion in 2023 according to the IMF, Guinea ranks at the bottom of the HDI ranking, ranking 181st out of 193 countries in 2022. According to the authorities, just under half of Guineans (43%) live below the national poverty line, which was estimated at 16,423 GNF/person/day (1.6 EUR) in 2020.

Furthermore, the economy remains largely informal, with an estimated share of 57.5% of GDP in 2021 and 96% of jobs in 2019. Furthermore, life expectancy at birth is estimated at 60.7 years in 2023. Guinea also suffers from recurring power outages (linked to water shortages that limit the hydroelectric production capacity of the Souapiti dam) and hydrocarbon supply difficulties since the explosion of the Conakry oil depot in December 2023 [2].

Politically, Guinea has been under a transitional regime led by a military junta since 2021, with a marked effort toward modernizing the administration and increasing transparency, as illustrated by the transition to the digital Official Journal [3].

2.2. Environmental Monitoring Analysis

Collection, Preparation of Samples and Materials

The samples were taken from five (5) operating sites on bauxite stocks formed after blasting or the use of "surface mining". These samples were prepared in the laboratory by crushing, quartering, drying, grinding, pulverizing, homogenizing, and distributing them into polyethylene and codified bottles.

Materials: Oven set at 105°C; Glass desiccator; OIC carbon analyzer-model 1010; Carbon dioxide absorber kit; Computer compatible with Windows 98 or later; Printer; Standard glassware: 100 ml volumetric flask and other standard la-

boratory glassware, washed with chromic acid and rinsed with double-distilled, CO₂-free water; Analytical solutions (phosphoric acid, sodium persulfate, hydrogen peroxide, etc.).

1) Industrial and Social Context

-Main Alumina Production Sites in Guinea

Alteo Refinery (formerly Friguia)

Fria Alumina Plant The Fria Alumina Plant, or Kimbo Alumina Plant, is the first alumina plant located in Guinea, on African soil. It enabled the town of Fria to experience rapid economic and demographic development. However, the plant was shut down for six years starting in 2012, with serious consequences for the town and its residents. It has been operational again since 2018.

The technique involves extracting the ore, bauxite, and then extracting alumina from it using a chemical process carried out in the plant. The alumina is then used to produce aluminum, but this is not done in Fria. The plant comprises two production units: bauxite grinding and alumina hydrate calcination. The alumina is stored in a 6000-tonne silo and then transported by train to the port of Conakry. The plant employed 1600 workers, including 370 supervisors, managers, and engineers, spread across the plant's various sectors [4].

-Guinea Bauxite Company (CBG)

Since 1973, CBG has been exploiting the Boké deposit, located on the Sangarédi plateau, which contains, on average, 53% alumina and 2% silica. The company is 51% owned by the Halco joint venture (45% Alcoa, 45% Rio Tinto, 10% Dadco) and 49% by the Guinean government. Proven and probable reserves are 340 million t at 47.1% Al₂O₃, with production in 2024 of 14.8 million t, transported by rail over 135 km to the port of Kamsar [5].

-United Company Rusal Group (Friguia)

The Russian group UC Rusal produced a total of 8.818 million tonnes in 2024, with the exploitation of the Kindia deposit, with a production of 3.016 million tonnes, that of the Friguia complex, built by Pechiney in 1957 and sold in 1997, with a production of 1.062 million tonnes, and that of the Dian-Dian project, in the Boké region, with a production of 4.740 million tonnes [5].

-Boké Mining Company (SMB)

SMB, controlled 22.5% by the Chinese group Shandong Weiqiao, associated with the Singaporean carrier Winning International Group (40.5%), the land carrier UMS (United Mining Supply) (27%), and the Guinean government (10%), began production in mid-2015, with production of 34 million tonnes, all exported to China, by 2022. The ore was initially transported by road to two ports, Katougouma and Dapilon, on the Nunez River, then on 8000-tonne barges to ships anchored on the high seas, as Guinea does not have a deep-water port, for delivery to the port of Yantai, in China. In June 2021, SMB inaugurated a 125 km railway line to transport the ore and is planning to build a refinery to transform bauxite into alumina. SMB's objective is to produce 38 million tonnes [5].

-Guinea Alumina Corporation

A subsidiary of the United Arab Emirates group, Emirates Global Alumina (EGA), is still developing a mining project at the Boké deposit with a capacity of 12 million t/y of bauxite. The first exports took place in August 2019 [5].

-State Power Investment Corporation (SPIC) Project

SPIC, a Chinese firm, launched construction of a new alumina refinery in Boffa in 2025, with a planned capacity of 1.2 million t/y, making it the largest alumina refinery in Guinea. This project also includes a 250 MW power plant to supply the refinery and feed electricity into the national grid. This site aims to strengthen local bauxite processing, in line with Guinea's strategy to increase local alumina production and reduce raw ore exports [6].

These sites constitute the major industrial pillars of the alumina and bauxite sector in Guinea, illustrating the coexistence of historic installations and ambitious new projects aimed at strengthening local added value while managing environmental and social impacts.

2) Description of Alumina Production Processes (Key Stages, Energy Consumption, Discharges)

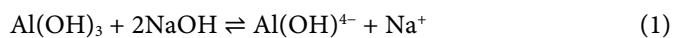
Generally, the process can be summarized in four steps: digestion, decantation/clarification, precipitation, and calcination.

❖ Digestion

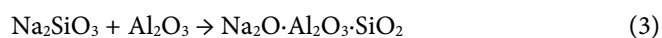
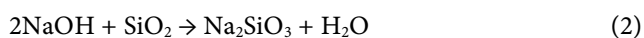
In the first stage, the bauxite from the mine is directly attacked by a concentrated hot sodium hydroxide solution (NaOH) after crushing and grinding. This operation solubilizes the aluminum into the aluminum tetrahydroxide ion due to its amphoteric nature compared to other constituents, which are insoluble at high pH, such as iron, titanium, calcium, REEs, and others. Indeed, the digestion operating conditions, including temperature, liquor concentration, residence time, and pressure, are determined based on the mineralogy of the starting bauxite.

To minimize sodium hydroxide consumption and contamination of the aluminate suspension due to the solubility of phyllosilicate clays, such as kaolinite, a desilication step is often necessary. Generally, the dissolution temperatures of aluminum hydroxides vary from 100°C to 260°C depending on the type of bauxite used. For example, the digestion temperature of a karst bauxite, where boehmite and diaspore, which are difficult to dissolve, predominate, is about 255°C under a pressure of about 3.5 MPa. The reactions involved in the digestion step, as well as the losses of sodium and aluminum in the desilication product, are presented by the following equations:

Digestion:



Desilication:



❖ Settling/Clarification

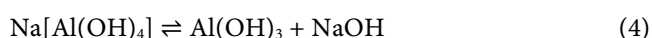
During the settling stage, the sodium aluminate liquor from digestion is de-

canted. Once the solid particles, composed of iron oxide, titanium, silicon, calcium, and other elements, have settled as a fine red sludge, they are washed several times with water, pumped out, and discharged to the sludge dams on site. The residual liquor is filtered and sent to decomposers to precipitate the alumina in hydrated form.

❖ **Precipitation/Decomposition**

Precipitation is the second step in the Bayer process. It is considered the reverse of the digestion step and can last several days. This step of the Bayer process precipitates the aluminate solution in the form of alumina trihydrate crystals. The characteristics of the resulting hydrate, such as particle size and morphology, depend on the precipitation conditions. The precipitation process is very complex and requires keeping the hydrate grains in suspension through slow agitation to prevent the sludge formed from settling at the bottom of the decomposer tanks. Equation (4) presents the reaction involved in the precipitation process [7].

Precipitation:



❖ **Calcination:**

In the calcination step, the wet hydrate is calcined to form alumina (Equation (5)), which is then used for the production of aluminum. This process is carried out in rotary kilns or static fluidized-bed furnaces, and at temperatures above 960°C. Alumina, a white powder, is the result of this step and constitutes the final product of the Bayer process, ready to be sent to aluminum smelters or the chemical industry [8].



In Guinea, bauxite mining is the first major step in the mining value chain, where the ore is extracted mainly in the Boké region, before being prepared by crushing and washing to remove impurities. The refining of this bauxite to obtain alumina is mainly done via the Bayer process, an innovative industrial process developed in 1887, which consists of digesting bauxite in a hot caustic soda solution to extract alumina in the form of hydrated aluminum oxide, then calcining it to obtain pure alumina, the essential basis for the production of aluminum.

These operations combine complex chemical and mechanical processes which, despite their efficiency, pose environmental challenges related to the management of residues (red mud) and high energy consumption. In Guinea, the modernization of facilities and the implementation of appropriate technologies are crucial to optimize this production while minimizing ecological impacts.

➤ Specific characteristics of the Guinean context (jobs, energy resources, regulatory framework).

Guinea's context is marked by the presence of significant natural resources, particularly energy and mineral resources. Guinea holds approximately two-thirds of the world's bauxite reserves, as well as resources in iron, gold, and other precious metals. The country also has significant energy potential, including hydroelectric

potential estimated at 6000 MW, solar, and wind power. However, only 2% of this hydroelectric potential is currently exploited. Despite this wealth, Guinea continues to face economic challenges such as low growth and significant poverty, affecting more than half of the population, a large proportion of whom live in rural areas.

In terms of employment, these mining and energy sectors represent significant opportunities but do not yet offset the country's economic and social difficulties.

Guinea's regulatory framework has recently been strengthened, notably by a presidential decree of July 2025 governing industrial activities within the country. This decree sets strict rules for the installation, operation, and control of industrial units, classified into six categories based on technical criteria (installed capacity, etc.). It aims to organize and regulate the industrial sector in accordance with current standards and to ensure better integration of industries within the legal framework [9].

The classification of industries is based on one of the first two assessment criteria, with the choice being made in favor of the one that places the activity in the highest category, as shown in **Table 1**. When the raw materials criterion is used, a maximum annual threshold, also specified in **Table 1**, is imposed by the regulations. Exceeding this threshold automatically leads to the reclassification of the installation in a higher category [9].

Table 1. Classification of industries according to their activities.

Category	Industry type	Installed power	Subject/Day	Subject/Year
A	Major industry	≥500 KWh	≥100 tonnes	Not specified
B	Intermediate industry	251 à 500 KWh	51 à 100 tonnes	≤30,000 tonnes
C	Medium-sized industry	26 à 250 KWh	≥50 tonnes	≤15,000 tonnes
D	Small industry	≥25 KWh	1 to 5 tonnes	≤1500 tonnes
E	Micro industry	≥10 KWh	≤500 Kg ou L	≤150 tonnes
F	Basic industry	≥5 KWh	≤50 Kg ou L	≤15 tonnes

3) Environmental Issues Related to Alumina Production

The alumina industry in Guinea, a strategic pillar of the national economy and a key driver of job creation, nevertheless raises major environmental issues related to waste management, energy consumption, and greenhouse gas emissions. In this context, the overall industrial transformation project (see **Figure 1**) is structured around three interdependent components aimed at establishing a sustainable and integrated alumina production sector in Guinea. Led by an experienced consortium, the Alteo Guinea refinery project is the central component: it involves the construction of a new-generation refinery, incorporating the most advanced technologies to significantly reduce the carbon footprint and meet the most stringent international environmental standards. This industrial system also relies on increasing use of renewable energy, particularly hydroelectricity, to limit dependence on fossil fuels, the main contributor to greenhouse gas emissions [10].

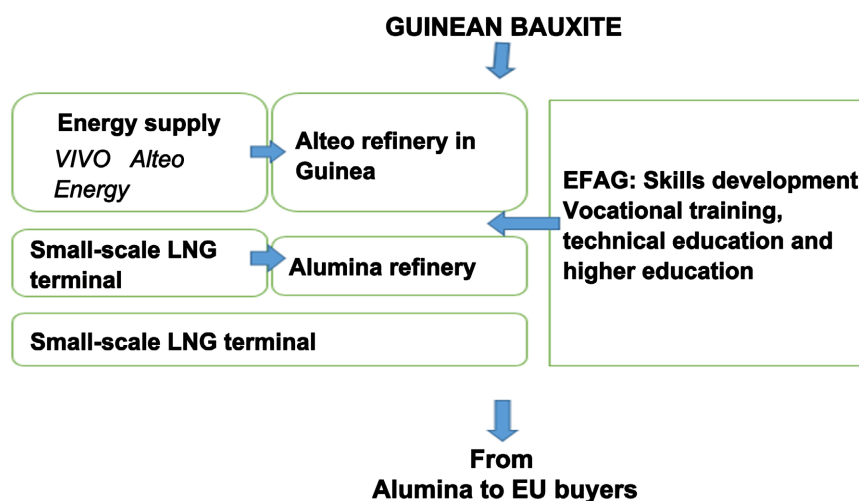


Figure 1. A comprehensive project with three interdependent components to create a processing industry in Guinea [10].

However, alumina refining remains a very energy-intensive process, with electricity consumption reaching more than 3000 kWh per tonne, which represents a major challenge in a country where access to reliable and clean energy is limited. In addition, classic problems persist, such as the management of bauxite residues, aqueous and atmospheric discharges, which are likely to impact local ecosystems. The historic Friguia refinery, operated by Rusal, has notably demonstrated the negative consequences of this industry on the environment and public health, prompting increased vigilance from authorities and NGOs [11].

4) Environmental Monitoring Methodology

Environmental assessment of extractive industries must combine physicochemical, biological, and social measures. In this study, monitoring was based on multimedia sampling (air, water, soil) around alumina production sites in Guinea. The management of bauxite residues (red mud) is one of the main environmental challenges. Chemical analyses were carried out on these residues, notably by atomic absorption spectrometry (AAS) and ICP-MS for the detection of heavy metals (iron, titanium, vanadium). Leaching tests were used to assess their potential for dispersion in soils and groundwater.

According to ISO, Life Cycle Assessment (LCA) is a relevant tool for measuring the ecological footprint. In this study, LCA was applied to the various stages of alumina production (extraction, transportation, calcination, and residue management) [12].

Existing electrical system: general condition of the public service.

Degraded generation, transmission, and distribution equipment.

Lack of 50 MW of static and rotating reserve to ensure grid stability.

Overall electrification rate of 12%.

Financial difficulties due to poor commercial performance characterized by the loss of approximately two-thirds (2/3) of the electricity produced.

Existing electrical system: The total installed capacity for the public, managed

by Electricité de Guinée (EDG), is 226.8 MW:

Hydraulic: 127.4 MW (Samou, Garafiri, Kinkon, Loffa, Tinkisso, and Samankoun) = 56%.

Thermal: 108.5 MW (Tombo 83.4 MW + 26.1 MW for 21 prefectures) = 44%.

In addition, 105 MW from mining producers (CBG, FRIGUIA, SAG, and LERO) is added.

Average consumption is 0.5 TOE/year/inhabitant, with an access rate of 8% - 12%.

83% to 88% of production supplies Conakry.

Condition of the Transmission Network (110/60/30 kV).

Low transit capacity of the 60 kV line:

Outdated protection systems.

Non-functional communication equipment.

Overloaded source substations; Tombo, Matoto, Sonfonia, Manéah, Mamou, Labé, etc.

No dispatching center.

Condition of the Distribution Network (20/15/6.3/5.5 kV).

Unprotected MV/LV distribution transformers:

Total lack of protective equipment.

Excessive overload (120-130%).

Transit capacity of MV lines exceeded.

Lack of operating flexibility for load transfer via another feeder. Completely outdated and inadequate internal networks.

High proportion of non-standard network: 36% of makeshift networks for MT and 80% for BT.

Etat du réseau de transport (110/60/30 kV).

Faible capacité de transit de la ligne 60 kV:

Systèmes de protection vétustes.

Équipements de communication non fonctionnels.

Surcharge des postes sources; de Tombo, Matoto, Sonfonia, Manéah, Mamou, Labé, etc...

Inexistence d'un centre de dispatching.

Etat du réseau de Distribution (20/15/6.3/5.5 kV).

Transformateurs MT/BT de distribution non protégés:

Manque total d'équipement de protection;

Surcharge excessive de (120% - 130%).

Capacité de transit des lignes MT dépassée.

Manque de souplesse d'exploitation pour la reprise des charges par un autre départ. Réseaux de l'intérieur complètement vétustes et insuffisants. Forte proportion de réseau hors-normes: 36% de réseaux de fortune pour la MT et 80% pour la BT [13].

Socioeconomic surveys and community participation.

- ❖ Questionnaires for local households: perception of nuisances, health problems, dependence on the river, and acceptability of measures.
- ❖ Semi-structured interviews: business managers, local authorities.

A participatory approach was incorporated. Semi-structured surveys of local residents were conducted to gather perceptions of impacts (dust, noise, water pollution) [14].

Among the main impacts identified, several deserve special attention.

a) Air Pollution

Air quality is significantly affected by lateritic dust and exhaust emissions from construction sites, earthmoving machinery traffic, transport trucks, and civil engineering works. Emissions from these vehicles and equipment increase the pollutant load in the atmosphere, with direct effects on the health of local populations and on visibility in the affected areas.

b) Impacts on Water Resources

Water degradation not only leads to land degradation, but also undermines entire viable ecological systems and affects economic and social development. Indeed, water resources are experiencing a continuous decline in quality and quantity due to agricultural exploitation and uncontrolled logging, particularly in tunnels and at spring heads. This situation, although experiencing regional disparities, is aggravated by the exploitation of construction materials (quarries) [15].

c) Loss of Wildlife Habitats and Poaching

Destruction of wildlife habitats and poaching. Land clearing caused by mining and industrial activities in Guinea is leading to a significant decline in natural habitats, particularly impacting small local wildlife, such as reptiles, birds, and rodents. Although the initial biodiversity in these areas is moderate, ecosystem disruption is a major source of concern. Furthermore, the increasing number of workers on the sites increases the risk of opportunistic poaching, affecting both wildlife and domestic animals in neighboring communities. This situation is exacerbating social tensions and increasing pressure on the preservation of local biodiversity.

3. Comparison of Guinean Practices with International Standards

Environmental practices in alumina production in Guinea are primarily based on national regulatory frameworks regarding the environmental impact of mining industries, particularly those related to bauxite mining and alumina refining. These practices include the conduct of environmental and social impact assessments (ESIAs) in accordance with the Guinean legal framework, which sets limits on air emissions, liquid discharges, and waste management, as well as mine site restoration measures. However, these national standards often have less stringent emission thresholds and control requirements than those recommended by international reference bodies, such as the World Health Organization (WHO) for

air quality, or the International Finance Corporation (IFC) standards used as a benchmark for mining and industrial projects.

For example, Guinea's annual limit for PM_{2.5} fine particles is set at 65 µg/m³, while the WHO recommends a limit of 10 µg/m³ to protect public health. This discrepancy highlights a significant gap between local and international standards, which may limit the country's ability to effectively prevent health and environmental impacts related to alumina mining and refining [16].

Furthermore, some large mining companies operating in Guinea, such as Compagnie des Bauxites de Guinée (CBG), aim to voluntarily align themselves with more demanding international standards, such as those of the Aluminium Stewardship Initiative (ASI), to manage and minimize their environmental impacts. This includes the adoption of best practices in bauxite residue management, the reduction of energy consumption, as well as the control of industrial waste. These initiatives are inspired by international standards to improve the sustainability of production and reduce the ecological footprint, sometimes going beyond national constraints [17].

Finally, Guinea, as the world's leading producer of bauxite, faces growing challenges in reconciling economic growth and environmental protection, requiring a gradual harmonization of its regulations with international best practices through reinforced environmental monitoring and adapted recommendations. Such an approach includes the implementation of standards such as those of ISO and IFC, as well as recommendations from World Aluminium, to guarantee responsible production that respects ecosystems [18].

4. Impacts and Priority Action Areas

Environmental mapping is an essential tool for understanding the interactions between industrial activities and natural environments. According to Zhao, Liu, and Zhang (2020), identifying impact areas allows for the targeting of the most effective corrective measures. In the case of alumina production in Guinea, four priority intervention areas were defined.

Zone 1: Production Sites

Bauxite processing plants primarily generate atmospheric emissions (dust, NO_x, SO₂), the production of red mud, and noise pollution. Priority measures include the installation of industrial filters, the construction of watertight containment basins, and the implementation of a continuous monitoring system for air and soil quality.

Zone 2: Watercourses

Nearby rivers and groundwater are exposed to liquid discharges and metal leaching from storage basins. Water pollution, identified as a major sustainability issue (World Bank, 2021; ISO 14040, 2006), requires the installation of effluent treatment plants, regular monitoring of pH and conductivity, and biological control of fish populations.

Zone 3: Riverside Villages

Nearby communities suffer from chronic exposure to dust, noise, and deforestation, generating social tensions and reducing project acceptability. Proposed responses include the creation of green belts, ecological compensation mechanisms (drinking water, social infrastructure), and environmental awareness programs.

Zone 4: Protected Forest Ecosystems

Classified forests and neighboring nature reserves face threats related to biodiversity loss and habitat fragmentation. To address these threats, it is essential to establish ecological corridors, strengthen wildlife monitoring, and promote reforestation in degraded areas.

5. Results

Application of the research methodology led to the following results:

Table 2 presents the results of total organic carbon analyses carried out at the CBG Chemistry laboratory.

Table 2. TOC analysis results.

N°	ID	T.O.C (%)
1	KLB-05	0.10
2	240527020	0.09
3	240527021	0.10
4	240527022	0.09
5	240527023	0.07
6	240527024	0.14
7	240527025	0.14
8	240527026	0.11
9	240527027	0.16
10	240527028	0.12
11	240527029	0.08
12	KLB-05	0.10
13	240527030	0.08
14	240527031	0.52
15	240527032	0.08
16	240527033	0.21
17	240527034	0.15
18	240527035	0.21
19	240527036	0.13
20	240527037	0.08
21	240527039	0.09
22	240527040	0.07

Continued

23	KLB-05	0.11
24	240527041	0.08
25	240527042	0.09
26	240527043	0.07
27	240527044	0.09
28	240527045	0.06
29	240527046	0.11
30	240527047	0.28
31	240527048	0.19
32	240527049	0.15
33	240527050	0.18
34	KLB-05	0.10
35	240527051	0.21
36	240527052	0.16
37	240527053	0.08
38	240527054	0.12
39	240527055	0.06
40	240527056	0.19
41	240527058	0.30
Moy (hors KLB-05)		0.14

- The results of the analysis of recent data on the environmental impact of alumina production in Guinea reveal that.
- The mining and metallurgical sector, although playing a key role in regional economic development, generates considerable environmental pressure.
- Surface mining causes substantial soil degradation, resulting in increased erosion and a significant loss of agricultural land, which is essential to the livelihoods of local populations.

Water resources are undergoing significant alterations, particularly through the contamination of rivers, streams, and groundwater, negatively affecting the domestic and agricultural uses of local communities.

- The metallurgical processes associated with production generate significant emissions of fine particles and polluting gases, contributing to the degradation of air quality and an increase in greenhouse gases.
- Bauxite residues, commonly known as red mud, pose a major environmental threat if improperly managed, with a high potential for water and soil pollution.
- Alumina production is characterized by high energy intensity, often relying on energy sources with high environmental impacts, which exacerbates the sector's carbon footprint.

These findings highlight the importance of rigorous management of environmental consequences, including compliance with international requirements and the implementation of corrective measures to minimize long-term negative impacts.

In Guinea, it is essential to share mining-related results (such as impact studies, revenues generated, or socioeconomic benefits) in a clear and accessible manner with all stakeholders: local communities directly affected by projects, the authorities that regulate and supervise the sector, and the investors who invest capital in it. Such transparency helps reduce suspicions of mismanagement or corruption, builds trust between stakeholders, and fosters a climate of collaboration. Making information available and understandable also gives citizens the opportunity to better defend their interests, which contributes to more responsible governance and greater project acceptability.

The study concludes that the implementation of systematic environmental monitoring is essential. The indicators measured not only quantify impacts but also provide an objective basis for guiding policies to reduce the ecological footprint in the alumina sector.

6. Discussion

Alumina production in Guinea, based primarily on the transformation of bauxite using the Bayer process, represents a major industrial challenge for the country, both in terms of its economic contribution and its environmental implications. Indeed, despite the strategic importance of this sector, its environmental impact remains a concern, particularly due to the significant amount of residue from the process, commonly known as red mud, as well as the high energy consumption it requires.

The results of the standard (KLB-05) are within the confidence limits defined for this standard (lower and upper limit).

The total organic carbon content ranges from 0.06% to 0.52%. Of 37 samples, 57% exceed the critical threshold of 0.10%. Monitoring oxalates is therefore essential during large-scale industrial testing.

Environmental monitoring of this industry is therefore imperative to ensure the sustainable exploitation of mining resources and to minimize ecological risks. Regular analyses of soil, water quality, and air around industrial sites should make it possible to quickly identify the most contaminated areas and elements, as well as evolving trends in pollution linked to the activity. Measurements of local biodiversity and monitoring of local human populations are also essential indicators to integrate into monitoring programs. These data are essential for guiding political and industrial decisions regarding impact mitigation.

To reduce the ecological footprint of alumina production, several recommendations can be considered. On the one hand, improving industrial waste management and treatment practices, particularly through red mud neutralization or recovery technologies, is essential. These toxic residues, if poorly managed, can have

lasting consequences for ecosystems and population health. The adoption of physical barriers, secure containment, and the progressive rehabilitation of affected areas must be systematized.

Furthermore, the transition to more efficient and energy-efficient industrial processes, as well as the increasing use of renewable energy sources, represents major levers for decarbonizing the sector. Optimizing water consumption and implementing recycling systems are also areas for improvement.

Finally, transparent governance, with the participation of local communities in monitoring and decision-making processes, will strengthen vigilance and promote development that respects social and environmental issues. In this sense, cooperation between the public and private sectors, as well as non-governmental organizations, is essential to implement coherent and sustainable action plans.

7. Conclusions

Regarding total organic carbon, 57% of the samples have a content exceeding the commercial threshold of 0.10%. This suggests the formation of oxalates in the factory, which will require measurements during industrial tests.

Environmental impact assessments exist, but their implementation and monitoring remain inadequate, leading to environmental pollution and tensions between the authorities, businesses and the populations concerned.

8. Recommendations

As a preventive measure, it is suggested to carry out stripping followed by exposure to rain for at least one season, in order to reduce by leaching the rate of organic matter in the raw bauxite and, consequently, that of organic carbon in the run-of-mine at the plant.

Companies must strengthen their internal systems for monitoring environmental, social, and human rights impacts by providing community teams and health, safety, and environmental departments with sufficient human, financial, and technical resources to ensure rigorous monitoring. An independent external audit, conducted every six months by auditors paid by the companies but operating autonomously, must assess these impacts and publish the reports. Transparency must be increased: companies must disseminate not only ESIA and environmental and social management plans, but also monitoring reports, translated into local languages and accessible online and in the affected areas. Respect for land rights remains imperative, with fair and equitable compensation for any land acquisition from communities or customary rights holders.

To make progress, Guinea could align its practices with these standards by strengthening emission controls and waste management, and by establishing permanent, transparent, and rigorous environmental monitoring.

Originality of the Study

Unlike previous studies that generally address the impacts of the mining industry,

this research stands out for its integrated approach, specifically contextualized to the Guinean case. By combining analytical field measurements, life cycle assessment (LCA) modeling, and a social survey of local populations, it constructs a comprehensive and operational assessment of the ecological footprint of alumina production.

The study's originality is also evident in the formulation of concrete recommendations adapted to the local context, covering both the recovery of waste and the establishment of inclusive environmental governance. It thus highlights the structural tension between, on the one hand, the contribution of the mining and metallurgical industry to economic development in West Africa, and, on the other, the considerable environmental pressures it generates.

The results obtained reveal that alumina production in Guinea leads to significant degradation of soil and water resources, as well as high emissions of particles and gases from combustion. The study finally highlights that the rigorous and sustainable management of red mud is a central issue, requiring concerted and resolute mobilization by the Guinean authorities in order to preserve the environment and the health of the population.

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Authors' Contributions

All authors contributed to the research and writing of this manuscript and have read the final version.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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