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Sustainably Growing Guinea's Bauxite-Aluminum Industry

Lynnette Widder, Thomas D. Pacioni and Ousmane Bocoum

Abstract

Guinea's bauxite-aluminum industry is undergoing significant expansion of investment, concession agreements, and in-country mining and refining operations. In 2018, UNDP-Guinea and Columbia University developed a framework that would evaluate this development against metrics for social and environmental sustainability, such as energy access and diversification, water quality, land use, biodiversity restoration, waste management, and community engagement. Current environmental impacts measured in GHGs, a metric both economic and environmental, were compared to potential impacts anticipated as a consequence of expansion. These anticipated impacts include enormous increases in countrywide GHG emissions and significant regional shortfalls in access to electrical energy. Case studies from the international bauxite-aluminum industry were then used to illustrate best practices for climate mitigation and adaptation and to describe opportunities for regional collaboration on shared-use energy and infrastructure development (e.g., hydropower used across West Africa, rail transportation) while achieving measurable benefits to communities, NGOs, regulators, and mining companies.

Keywords: Guinea, bauxite, aluminum, alumina refining, greenhouse gas emissions, GHG, sustainable mining, climate mitigation, climate adaptation, industrialization, regional investment, infrastructure, cumulative impacts, environment

1. Introduction

The Republic of Guinea is rich in natural resources yet, since its independence in 1958, has struggled to transform that advantage into durable economic and social development. The small country has over a quarter of the world's proven bauxite reserves, approximately 7.4 billion metric tonnes (t) [1, 2], more than any other nation. Bauxite is the primary ore used to produce aluminum; aluminum alloys are used to manufacture countless items around the globe. Still, Guinea's bauxite mining industry did not grow substantially between the 1960s and 2015 [3]. Thus, Guinea's government [4], along with the World Bank [5], African Development Bank [4, 6], and others [7], has identified Guinea's mining sector with economic growth, infrastructure development, poverty reduction, and social well-being. Recently, foreign direct investment (FDI) has fueled dramatic increases in Guinea's bauxite-aluminum industry (**Figure 1**). This growth presents new challenges as governments and industries worldwide have focused more and more on (GHG)

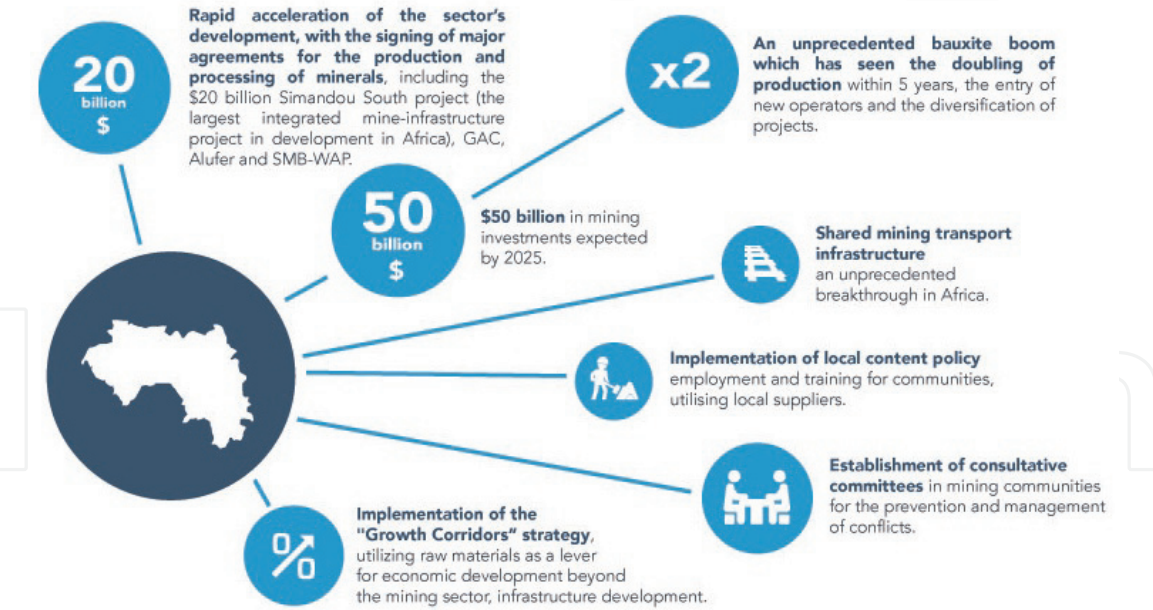


Figure 1.
Rise of Guinea's mining sector.

emissions and climate adaptation strategies. Notably, Guinea formalized a commitment to the United Nations Framework Convention on Climate Change (UNFCCC) by publishing its intended national development goals (INDCs) and sustainable development strategy priorities [4] in 2015.

Like most developing countries, Guinea lacks capacity to meet its INDCs alone. Recognizing this widespread need, UNFCCC created the Green Climate Fund (GCF) as a mechanism to encourage climate change adaptation and mitigation by matching private sector investment funds. The GCF's eligibility requirements are quite strict, and programmatic assistance is often needed to qualify. Hence, in 2016 Guinea requested and received a GCF Readiness Programme grant to help build its capacity. The UNDP, an accredited partner of the GCF [8], led Guinea's Readiness Programme and, as part of capacity building, sought out Columbia University to develop tools to engage Guinea's private sector in sustainable mining practices. This chapter summarizes that project's conceptualization, methods, and results, including generalized insights into public-private collaborations. The Readiness Programme wrapped up in December 2018 with Guinea's National Designated Authority established and prepared to articulate initiatives, mobilize private sector engagement, and develop a robust GCF Country Programme plan. Thus, Guinea is now fully equipped to access the GCF funding.

1.1 Conspicuous sustainability resources

The UN's Sustainable Development Goals (SDGs) 8, 9, 11, and 17 integrate responsible resource extraction regimes into sustainable development. At present, a confluence of factors—new mining concessions, presidential agenda, civil society organization activity in the mining regions, and not least of all the GCF matching funding—has created opportunities to solidify sustainable mining practices. UNDP-Guinea's decision to ask Columbia University for support with this acutely relevant work underpins the notion that student-based research can be an effective impetus to useful and compelling outcomes when it is backed by in-depth involvement of seasoned researchers like Widder and Pacioni, on-site face-to-face interactions, and a commitment to collaboration. This project fostered genuine engagement from stakeholders in industry, government, and local NGOs by uncovering pathways to

influence local technical approaches, regional development, and national policy. Because the project was objective and academic, leveraging resources not typically available (e.g., Columbia University's degree programs in sustainability), its approach offers a unique methodological reference.

1.2 Economic, environmental, and social context

The seemingly dissonant condition of abundant natural resources coupled with highly limited economic and social development is not uncommon in West Africa [6]. The challenge of remedying that deeply rooted condition is daunting because economic development, social development, and environmental protection are overlapping and often conflicting components in a highly complex system (i.e., sustainable development). To help determine needs, the UNDP calculates a Human Development Index (HDI) based on inputs including life expectancy, education, and per capita income. Of UN's 189 member nations, Guinea's HDI ranks 175 [9]. In fact, all West African nations are ranked in the lowest quartile. To vitalize sustainable development in Guinea, UNDP-Guinea focuses specifically on poverty reduction, climate change risk, and peace building and governance [10].

With a population of 12.7 M [11], Guinea ranks among the world's least developed in infrastructure [12] and, until very recently, FDI [13]. However, in a remarkable change from decades of economic stagnation, gross domestic product (GDP) rose 10+% in both 2016 and 2017, largely due to mining sector expansion [13, 14]. In accordance with its strategic plan [4], Guinea's Ministry of Mines and Geology actively developed new concessions and promulgated a special economic zone (SEZ) for the Boké Region in 2017, underscoring its importance to the bauxite-aluminum industry. Of particular note, the bauxite-aluminum industry's current boom is borne largely of FDI from China [15], the UAE [16], Russia [17], and, to a lesser extent, Iran [18], France [19], the USA [20], the UK, Australia, India, and the Netherlands in joint ventures with federal ownership. Moreover, a consortium of mining companies funded a new trade organization, Guinea's Chamber of Mines, to communicate and represent private mining sector interests.

As the World Bank describes in its report on Guinea's mining sector, the bauxite industry's need for infrastructure offers crucial potential for industrialization and service sector development [14]. For example, recent investment in rail transport from Guinea's mining hub in the Boké Region to its commercial port originated in the private sector working through the Chamber of Mines. Potentials for the transportation and service sectors to provide local employment exceed that of the largely automated mining industry, especially if that development is part of a regional network linking nearby landlocked economies to Guinea's port. In fact, Guinea's abundant waterways and other freshwater assets have high regional importance and must be part of any sustainable development plan. Nonetheless, difficulties remain in defining and enacting mechanisms to distribute the mining sector's benefits and to enact good governance, community enhancement, and environmental mitigation.

1.3 Regulatory and policy context

A lack of transparency about mining concessions and practices, poor communication with communities impacted, inadequate or poorly timed remuneration for agricultural land, and the tendency among foreign mining companies to import everything from power plants and fuel to workers from their home countries have led to civil unrest, especially in the Boké Region [21]. Riots, destruction of property,

and disruption of electrical and transportation infrastructure hobble extraction and threaten its continued build-out.

Although regulations requiring environmental impact reports are in place, Guinea's Ministry of Environment is underfunded and underequipped to monitor and enforce industry commitments [22]. A recent Human Rights Watch report [22] illustrates impacts of poorly enforced regulation on farmers' livelihoods, civil society, and citizen confidence. Reports of waterway degradation from dust released during open-pit mining suggest that the current boom is adversely impacting fisheries, mostly practiced at artisanal scale, which is the country's other primary employment sector [23]. Because Guinea encompasses the source and/or course of nearly all major West African rivers, any water quality or flow degradation will have considerable regional ramifications. Further, these impacts will have a compounding negative effect on region-wide ecosystems as underscored by independent climate change models predicting increased desertification in West Africa [14], especially in the transition zone between the Sahara Desert and the southern savanna (i.e., Sahel).

1.4 Current funding mechanisms

After clarifying Guinea's willingness to meet its responsibilities under the UNFCCC's Paris Accord, UNDP-Guinea turned its attention to the bauxite-aluminum industry because it has overwhelming bearing on Guinea's sustainable development and because it is among the few industries with the capacities to co-finance GCF projects. Currently mining companies are required to pay a small proportion of their profits as a "royalty" intended for use in federal remediation projects. Although mining companies may see the benefits of addressing the cumulative impacts of their activities, this mining royalty modality, the primary modality for participation, is not sufficiently robust. Existing mechanisms designed to ensure effective application of legal and regulatory instruments for mining development are very weak and constitute a hindrance for crowding in private sector investment.

However, one might find opportunity rather than conflict where mining investment and civil society participation intersect. This study landed on the concept of "shared use" to describe these synergies (described below). Accordingly, and as a direct result of the collaborative activities described, UNDP-Guinea is developing a work scope for integrated management of the coastal region that has been impacted by mining activities and erosion, with co-financing of USD 11 M from the GCF and the Chamber of Mines. This demonstrates how the GCF created opportunity to couple Guinea's rapid industrialization to its INDCs.

2. Project design

2.1 Objectives

The overarching project objective was to engage Guinea's private-sector mining companies in productive dialog regarding sustainable mining practices, both current and future. Specific goals included the following: (a) identify public-sector stakeholders that could champion sustainability-based initiatives and private-sector stakeholders with expertise in sustainable mining practices; (b) determine the industry's current direct GHG emissions and potential impacts from near-term industry growth; (c) in light of enormous pressure to expand, identify perceived and actual barriers to sector growth and perceived barriers to more sustainable practices; (d) describe proven best practices for sustainability in mining that are applicable and appropriate in Guinea; (e) assist in positioning the mining sector to help meet Guinea's INDCs

and to access new forms of capital (e.g., GCF); and (f) provide UNDP-Guinea a model for implementing such initiatives in the future.

Columbia's conceptual approach was threefold: (1) establish credibility with private- and public-sector stakeholders; (2) develop an unbiased overview of the industry's likely or typical operations, challenges, risks, and opportunities relative to environmental and social conditions; and (3) share pragmatic approaches to sustainable mining in a face-to-face forum to (i) enhance Guinea's knowledge base, (ii) elicit industry feedback on specific tactics used currently and challenges foreseen, and (iii) leverage dialog to form a collaborative effort among stakeholders to share knowledge and to focus on achievable sustainability goals.

2.2 Scope and methods

In spring 2018, Dr. Lynnette Widder, a Columbia University professor of sustainable development and urbanism, assembled a team that included technical advisor Thomas D. Pacioni whose decades-long experience in extractives and advanced degrees in geology and sustainability management equipped him to guide research and analysis and four graduate students recruited based on academic performance from Columbia's Master's Degree programs in Sustainability Management and in Public Administration and Development [24]. UNDP-Guinea committed to monitor progress and facilitate communication with Guinean organizations, and their operational support and strategic input proved invaluable. The work scope was modeled on the GCF's 2015 Readiness Proposal for Guinea [25] and was completed in two distinct phases. Columbia's research team initially completed:

- **Literature reviews** on (a) Guinea's current and planned capacity expansion of bauxite-aluminum operations; (b) inputs, outputs, throughput volumes, and potential sustainability impacts from operations; (c) typical GHG emission factors correlated to production; (d) standards and guidelines used elsewhere that could be adapted to Guinea; and (e) successful implementation of sustainability practices in bauxite mining under environmental and social conditions similar to Guinea's.
- **Interviews** with mining industry insiders with expertise in environmental, social, and governance (ESG) practices, financing capital projects in international extractives, and Guinea's regulators, including: a representative of the International Council on Mining and Metals (ICMM), a biodiversity consultant working in Guinea's mining sector, International Finance Corporation (IFC), Power Africa (a USAID program), an independent consultant, Columbia's Center for Sustainable Investment (CCSI), Guinea's Ministry of Energy and Water Resources, and Electricité de Guinée.
- **GHG emissions** were estimated for (a) current actual bauxite volumes reported; and (b) near-term future conditions based on conservative estimates of published expansion plans.
- **Case studies** were selected that (a) apply directly to Guinea's bauxite mining conditions; (b) mitigate effectively and realistically a spectrum of sustainability risks; (c) cross-reference industry standards; (d) incentivize action on environmental and social performance; and (e) could facilitate knowledge sharing and initiate a dialog with Guinea's mining companies, leading to future collaborative data gathering and discussion of best practices.

Subsequent to Phase 1, and with facilitation support from UNDP-Guinea's Ousmane Bocoum, Widder and Pacioni expanded work on qualitative and quantitative drivers that included (a) field-based research in Guinea to isolate data gaps and to verify and/or update Phase 1 data; (b) interviewing executives from Guinea's Chamber of Mines and UNDP-Guinea's local ESG programs, in part to gain insight into the relationships among mining's actual (i.e., on-the-ground) environmental and social drivers; (c) beginning to explore methodologies for developing shared infrastructure in transportation and energy that can benefit communities and private-sector stakeholders durably; (d) developing an advocacy strategy to prove how sustainability-based best practices will reduce intense social pressures by expressing a longer-term growth approach that includes generational community needs, not only annual revenues; (e) leveraging a recently created consortium of bauxite mining companies in the Boké Region dedicated to cross-border biodiversity to disseminate and access critical data; and (f) leading a workshop to share sustainable findings and support collaboration and/or friendly competition among bauxite mining companies in Guinea.

2.3 Limitations

The study was not comprehensive in scope but instead was limited to readily available data. Although financing mechanisms were discussed, neither a detailed financial analysis nor a review of potential capitalization strategies was completed. Rather, the results of a non-funded academic exercise were expanded in the hope that tangible progress in private-sector engagement could further the UNDP/GCF's Readiness Programme.

3. Academia's POV: benefits and value

Although the benefits of university research to policy makers are well established, less attention has been given to the role that academic coursework can play. For this project, UNDP-Guinea prioritized academic objectivity. This relationship allowed the team of students and faculty to retain full academic freedom, to conceptualize the project's scope, and to reframe questions as warranted by iterative research results.

The team's independent position translated into access to subject-matter experts who might otherwise have treated their knowledge as proprietary, including international trade organizations, industry representatives, independent finance and science consultants, development aid organizations, and researchers from other academic institutions. Because the workshop format of the research project led to broad-based action items, Guinea's bauxite-aluminum industry representatives and regulators could consider its outcomes without concerns about conflicting agendas.

4. Production processes

Bauxite, a sedimentary rock, is the primary ore used to produce aluminum. In turn, aluminum alloys are widely used [26] to manufacture all types of vehicles, mobile phones and electronics, machinery, building construction materials, and household items. Transforming bauxite into aluminum is a three-step industrial process (**Figure 2**), each step having social and environmental impacts (e.g., GHG emissions). Based on typical worldwide production data, approximately 5.54 t of extracted bauxite will produce 2.25 t of alumina which, in turn, will produce 1 t of aluminum [27].

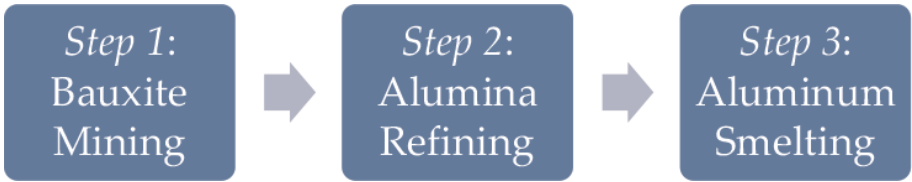


Figure 2.
Bauxite-aluminum process steps.

4.1 Bauxite-aluminum production

Bauxite mining—In Guinea, bauxite is mined from open pits, crushed, and washed on site with water to reduce dust and remove some impurities. The material is then screened and dried, producing beneficiated bauxite and wastewater, and then transported to an alumina refinery. At most bauxite mines around the world, wastewater is retained in settling ponds for reuse [28]. This is likely true in Guinea; however, specific company practices are not publicly available. Most of Guinea’s beneficiated bauxite is shipped abroad for refining.

Alumina refining—Beneficiated bauxite is then refined into alumina (i.e., aluminum oxide, Al_2O_3) using the Bayer process, wherein hot caustic soda is added to dissolve the aluminum compounds. Insoluble residue (i.e., red mud) is then filtered out, and alumina is precipitated. The red mud is washed to recover as much caustic as practical and then disposed.

Aluminum smelting—Smelting (anode paste production, electrolysis, and ingot casting) is the process by which alumina is dissolved in sodium aluminum hexafluoride (cryolite) at $1,000^\circ\text{C}$ and then placed in a cell with carbon (typically graphite) cathodes and anodes. Electrolysis oxidizes the anode’s carbon to carbon dioxide (CO_2), and aluminum ions are reduced to aluminum metal at the cathode.

4.2 Resource use and impacts

Potential environmental impacts of bauxite-aluminum production include top-soil destruction, dust generation, overuse of freshwater supplies, wastewater releases, and GHG emissions. Resource inputs and non-GHG waste based on typical production data are summarized in **Table 1**, and qualitative summaries are provided below.

Bauxite mining—Mechanical mining causes dusty conditions, and airborne particulates are both a direct respiratory risk and the primary source of reddish deposits in the areas around. Energy inputs at this phase are mostly diesel used in bulldozers, excavators, and haul trucks. While Guinea’s mining wastewater may be recovered as a general practice, there are reports of surface water impacts [22]. This means wastewater management may not be adequate to protect Guinea’s all-important waterways.

Alumina refining—Refining requires substantially more water and electricity than mining. Disposed red mud is high in pH and salinity. In addition, metals and natural background radioactivity from its parent bauxite are often concentrated in red mud. Although there are potential uses for red mud, the international rate of reuse is only 2–3% [32]. Other by-products of alumina refining include hydrocarbons, suspended solids in water, and air emissions of nitrogen dioxide, sulfur dioxide, and mercury [28, 30]. Thus, risks to human health and surrounding ecosystems from alumina refining [33] dramatically eclipses.

Aluminum smelting—Smelting requires yet another order of magnitude increase in energy input. Water requirements are also significantly greater than

	Bauxite mining (per t of bauxite ore extracted)	Alumina refining (per t of alumina refined)	Aluminum smelting* (per t of primary aluminum smelted)
Fuel input	1.5 kg [29]	100 kg [30]	Not available
Electricity input	5 kWh [29]	150 kWh [29]	14,000 kWh [31]
Water input	0.6 m ³	8 m ³ [31]	~20 m ³
Waste output	0.00095 t dust	1–1.5 t	0.05 t
	Bauxite mining (per t of aluminum)	Alumina refining (per t of aluminum)	Aluminum smelting* (per t of aluminum)
Fuel input	8.3 kg	225 kg	Not available
Electricity input	27.7 kWh	337.5 kWh	14,000 kWh
Water input	3.3 m ³	18 m ³	~20 m ³
Waste output	Negligible	3.4 t	0.05 t

*Electrolysis process only, excludes anode production and ingot casting.

Table 1.
Inputs for bauxite-aluminum production.

mining or alumina refining. Smelting also produces air emissions of fluorides and hydrocarbons [28].

5. Guinea’s bauxite-aluminum industry

Figure 3 shows the location and number of concessions, or permits to operate, for bauxite mining and alumina refining. Mining is largely centered in northwestern Guinea in the Boké Region’s SEZ. The majority of concessions are held in whole or in part by foreign mining organizations that have incorporated Guinean operating companies in conjunction with the Republic of Guinea’s government. Through 2015, Compagnie des Bauxites de Guinée (CBG, a.k.a. Guinea Bauxite Company) accounted for >75% of extracted bauxite. Guinea’s government holds a 49% interest in CBG, with the balance held by an international consortium. The remaining 20–25% of Guinea’s bauxite industry prior to 2016 was controlled by Russia’s RUSAL, operating three wholly owned subsidiaries. Large-scale growth began in 2015 (primarily) by expanding existing concessions and granting new concessions, with new mining operations coming on line in 2016. Guinea’s government controls 10–15% of most of the new concessions.

5.1 Current bauxite-aluminum production

Bauxite production for 2008–2018 (estimated) is provided in **Table 2**, and a summary of mining companies operating in Guinea is provided in Appendix A. Despite more than a half-century of bauxite mining, only one alumina refinery has been established in Guinea and its operation has been sporadic and largely inconsequential. No smelters have yet been constructed.

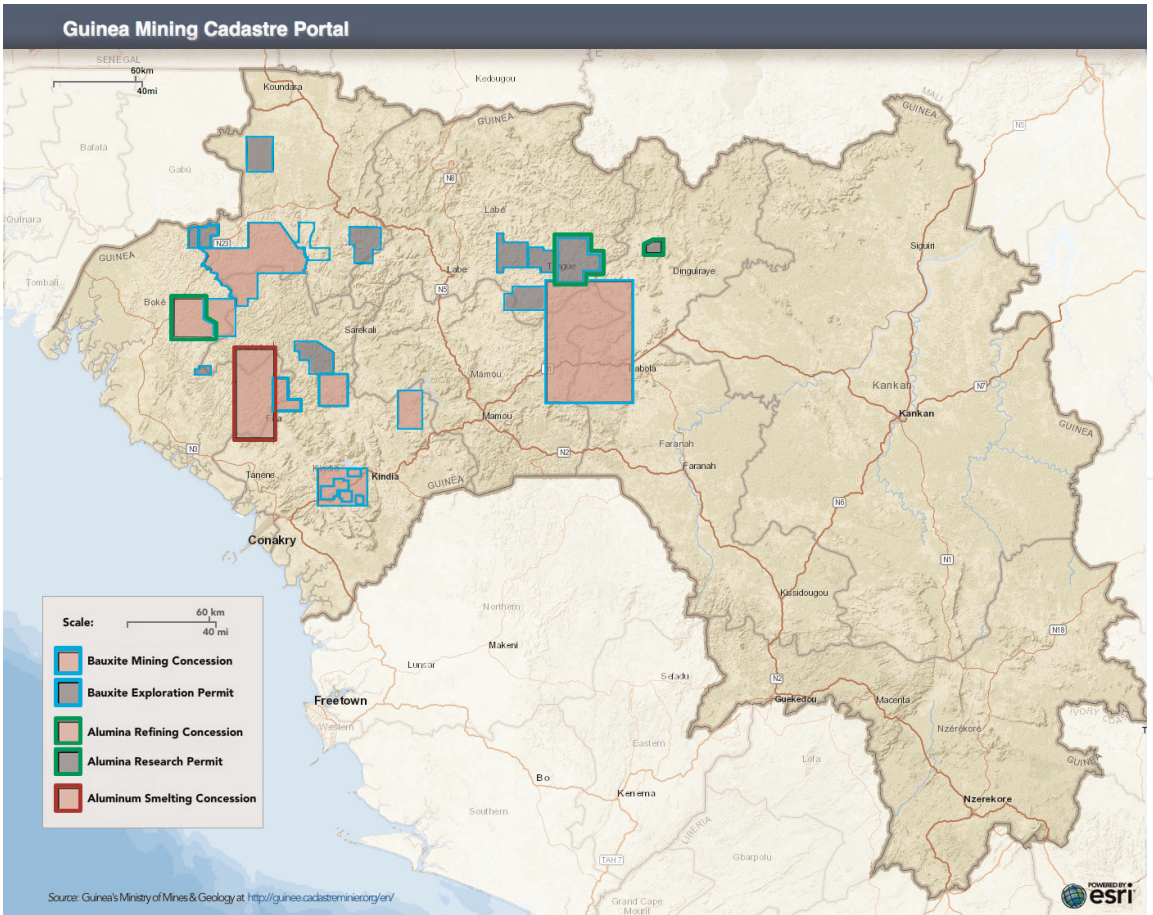


Figure 3.
Location of Guinea’s bauxite-aluminum concessions.

Year	Bauxite production (Mt) [3]	GHG emissions (MtCO ₂ e)
2008	18.5	0.33
2009	15.6	0.28
2010	17.4	0.31
2011	17.6	0.32
2012	17.8	0.32
2013	18.8	0.34
2014	17.3	0.31
2015	18.1	0.33
2016	31.5	0.57
2017	46.2	0.83
2018*	50.0	0.90

*Estimated.

Table 2.
Bauxite production and GHG emissions, 2008–2018.

5.2 GHG emissions

Although it does not integrate water pollution, soil pollution, or other types of air pollution relevant to the funding opportunities offered by the GCF, GHG emissions is the primary metric used to determine climate mitigation and adaptation

needs. For the purpose of calculating conservative GHG estimates, the proportion of hydroelectric power in the industry’s overall energy mix was assumed to be consistent with regional averages in Africa (i.e., 43% [34]), compared to Guinea’s actual proportion of hydroelectric power, approximately 56% [35]. This GHG analysis only considered the industry’s current direct emissions, and not secondary emissions from transportation between facilities or to end users. GHG emissions are expressed throughout this chapter as t of CO₂ equivalents or tCO₂e. **Table 2** and **Figure 4** summarize annual bauxite-aluminum production and GHG emissions for 2008–2018. Emission factors (EFs) used to calculate GHG emissions for each step in the aluminum production process are summarized in **Table 3**. EFs are provided per t of material produced in each step and per t of aluminum produced across each step. To determine EFs, the relative proportions of material required to produce 1 t of aluminum (described in Section 4) were assumed.

Consistent with Guinea’s strategic plan, bauxite production has increased rapidly since 2016. Guinea’s alumina refinery had not been operating, so recent GHG emissions were negligible, though refining resumed in early 2018.

5.3 Expansion plans and future GHG emissions

Since 2015 Guinea’s government has consistently signaled strong interest in expanding bauxite mining, as well as in-country alumina refining and aluminum smelting. Specifically, all new mining concessions have included rights for alumina refineries, most notably a USD 2.8 B investment from the Chinese company

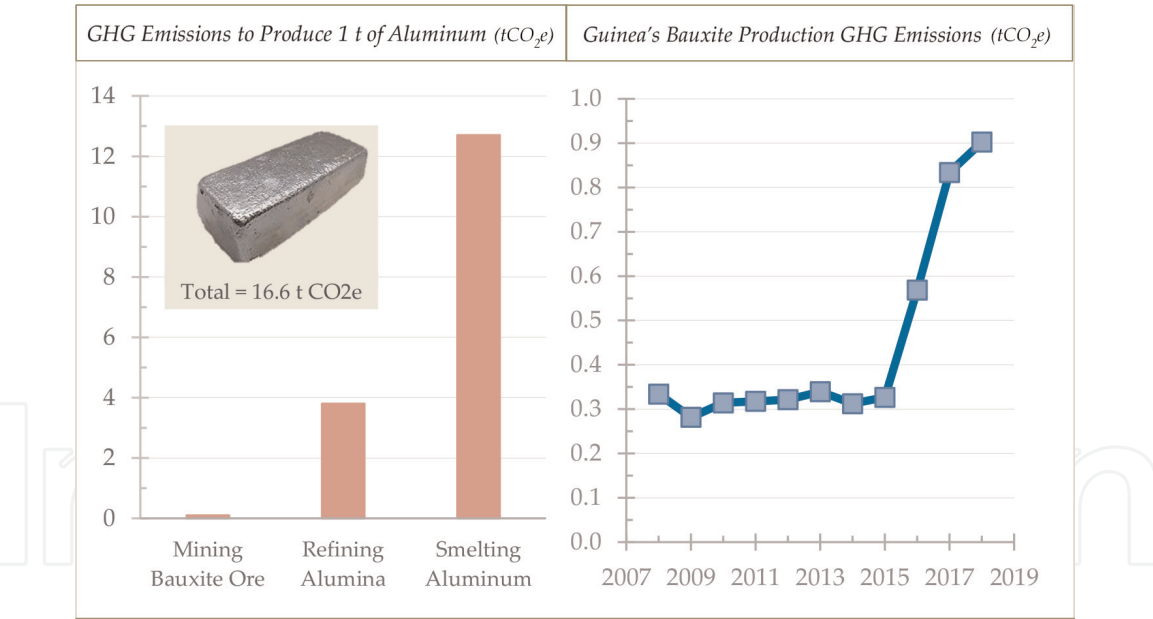


Figure 4.
Current GHG emissions.

Process stage	GHG EF	GHG EF normalized to 1 t aluminum
Bauxite mining	0.02 tCO ₂ e/t of bauxite	<0.1 tCO ₂ e/t of aluminum
Alumina refining	1.69 tCO ₂ e/t of alumina	3.8 tCO ₂ e/t of aluminum
Aluminum* production	12.7 tCO ₂ e/t of aluminum	12.7 tCO ₂ e/t of aluminum
Total to produce 1 t aluminum		16.5 tCO ₂ e/t of aluminum

*Includes anode paste (0.6 tCO₂e) + electrolysis (11.9 tCO₂e) + ingot casting (0.2 tCO₂e).

Table 3.
Average GHG EFs by process [34].

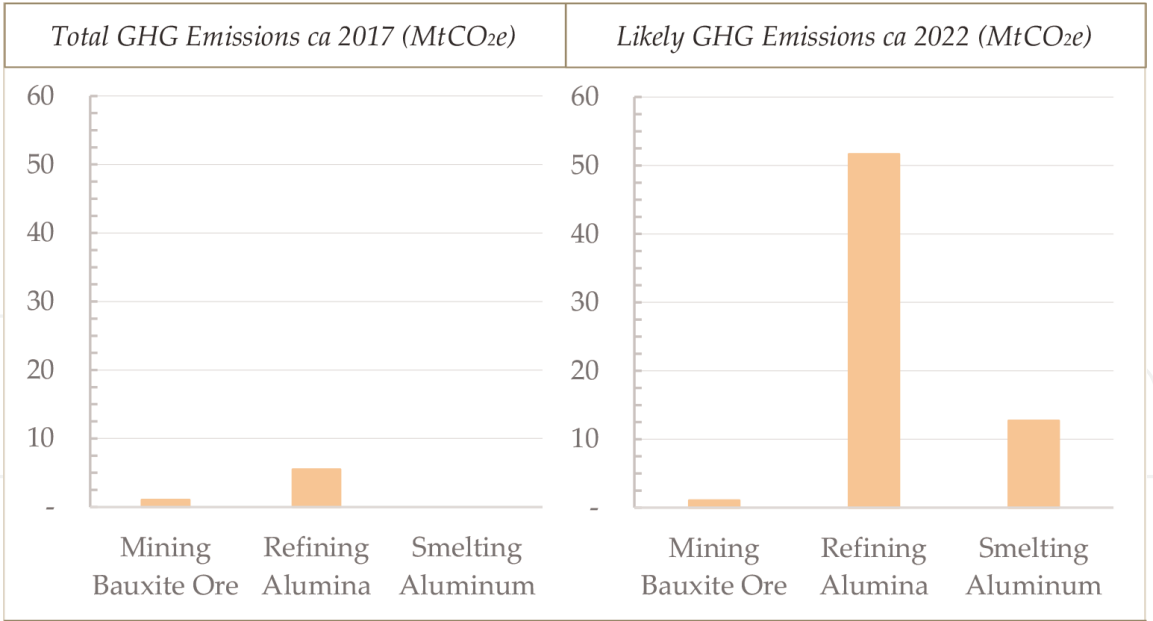


Figure 5.
Future GHG emissions.

TBEA [36]. TBEA plans to bring its alumina refinery online by June 2021 and to start smelter construction by 2025. (Because TBEA’s concession is not yet available, it is not included in Appendix A). In addition to private-sector funds, the World Bank’s [37] investment matching program has facilitated the mining industry’s rapid expansion. Guinea’s stated goal is to grow extraction refining from 0.6 to >1 Mt by 2024 [38], thereby boosting GDP and generating considerable demand for local employment, though it is not clear that local workers will benefit from these new concessions. More concerning than the lack of transparency about staffing plans in these new concessions is the extraordinary increase in GHG emissions that will accompany alumina and aluminum productions (**Figure 4**). The likely impact on near-term GHG emissions is shown in **Figure 5**.

5.4 Regulations and standards

International, sectorial, and industry standards can ensure that mining companies follow best practices, especially if mutual monitoring by competing bauxite companies of one another’s compliance was embedded in compliance plans. The Guinea Sustainable Bauxite Mining Consortium, founded as a vehicle for GCF support, is one such opportunity. Additional standards are published by the IFC, the ICMM, the Aluminum Stewardship Initiative (ASI), and the Business and Biodiversity Offsets Programme (BBOP). However, because few of the companies operating in Guinea are publicly traded and therefore less likely to feel pressure from shareholders regarding accurate and timely environmental reporting, consensual oversight among peer companies is particularly important. Guinea’s laws and industry guidelines include provisions and methods for rehabilitating exhausted mines with local collaboration [39]. However, this has had limited success in the Boké Region [22].

6. A shared values approach to solutions

Given limitations on Guinea’s capacity to enforce its regulatory requirements and to create transparency around the environmental impact assessments required by law, it was prudent to look to other, less conventional pathways to help prioritize mining and refining processes that will decrease the magnitude of environmental

Mining companies and trade organizations: Chambre des Mines de Guinée, Alliance Minière Responsable (AMR), Alliance Mining Commodities (AMC), Alufer Mining, Compagnie des Bauxites de Guinée (CBG), Emirates Global Aluminum (EGA), Société Minière de Boké (SMB)	Academia: Columbia University - The Earth Institute, L'Université Gamal Abdel Nasser de Conakry- Centre d'Etude et de Recherche en Environnement (UGANC-CERE)
Nongovernmental organizations: Green Climate Fund, UNDP-Guinea, United Nations Children's Fund (UNICEF)	Guinean government ministries: Ministry of Mines and Geology, Ministry of Environment
English translations of organizational names are provided in Appendix A.	

Table 4.
Workshop participants.

and community damage. Conflict around competing resource needs is inevitable unless synergies and compromise are integrated. This points to consideration of shared values, an approach that has already realized rail and port improvement co-funded by mining companies.



With collaboration, Guinea’s hydropower potential may be used to leapfrog GHG impacts while also benefiting underserved rural communities. Guinea is the source of at least a dozen major West African rivers and a similar number of regional rivers, and could potentially generate 19,300-26,000 GWh of hydropower annually [35, 40]. The present installed capacity, subject to considerable seasonal fluctuation, is 0.5–0.6 GW [41]. Still, rural electrification is less than half the national average (11 vs. 26%). System build-out in which the bauxite industry can serve as an anchor client coupled with careful planning and monitoring to ensure biodiversity and waterway health could provide enormous national and regional benefit in perpetuity.

6.1 From shared use to shared solutions: a successful workshop

On June 29, 2018, the results from both phases of this study were presented in a workshop chaired by the Chamber of Mines with extensive participation from mining companies and organizations (Table 4). Stakeholders applauded UNDP-Guinea and Columbia University and described the workshop to Mr. Ousmane Bocoum (UNDP-Guinea, June 29, 2018) as “solutions served on a plate”. Debate on best practices inspired mining companies to discuss remediation strategies they are already practicing, making public efforts already underway (because they privately held, mining companies in Guinea have neither shareholder reporting nor robust corporate social responsibility reports). The workshop culminated in discussions on the benefits that mining companies would gain by more extensive knowledge sharing among companies, and how that knowledge sharing would help reach sustainability goals.


6.2 Case studies

Case study no. 1: Land Rehabilitation for Bauxite Mining Objective: Enhance biodiversity by landscaping closed areas with native plants Solution: Nucleation method at bauxite mine in Brazil’s Amazon region	
Methods/technical approach: <ul style="list-style-type: none">Integrate solutions for closing tapped-out areas, enhancing biodiversity, and develop local economy	Standards/regulatory drivers: <ul style="list-style-type: none">IFC 6: Biodiversity, IFC 4: Community, IFC 1: Assessment and Management of Environmental and Social Risks and Impacts

<ul style="list-style-type: none">• Use land-use offsets to drive toward footprint-neutral goal• Hire locals to collect and plant seeds for indigenous vegetation• Leverage natural processes to build microenvironments that reduce landscape fragmentation• Create topsoil from vegetation and rainwater• Reduce runoff by contouring land surface• Create wildlife shelters• Underwrite local biodiversity conservation program	
<ul style="list-style-type: none">• ICMM 6, 7, 9 (10, reporting)• ASI Principle 8 biodiversity, 9.7 local communities• BBOP principles and mitigation hierarchy	
Location: Brazil	
	
<ul style="list-style-type: none">• Area population: 35,000• High population growth• Very high poverty rate	
Benefits/business value:	
<ul style="list-style-type: none">• Reduce closure/restoration cost by 40%• Reduce long-term liability from biodiversity loss beyond fence line• Bolster reputation by spending restoration expenses locally• Help achieve strategic goal of footprint-neutral mining	
Case study no. 2: Community Engagement for Bauxite Mining	
Objective: Improve transparency and stakeholder dialog to reduce social unrest	
Solution: Dialog and support for local communities around bauxite mine, Brazil	
Methods/technical approach:	Standards/regulatory drivers:
<ul style="list-style-type: none">• Host annual intersectoral forum with an international education foundation to include 60 civil society organizations and local authorities• Use itinerant dialogue process to bring company reps into communities for regular meetings• Offer access to monitor local water quality during extreme weather events and support local, recovery efforts and services• Involve local NGOs as third-party observers in community-related actions• Use open-house initiative to provide scheduled facility tours for local residents	<ul style="list-style-type: none">• IFC 4: Community, IFC 7: Indigenous Peoples, IFC 1: Assessment and Management of Environmental and Social Risks and Impacts• ICMM 1, 4, 10• ASI Principle 9.7 local communities, 3.4 stakeholder complaints, grievances, and requests for information
Location: Brazil	
	
<ul style="list-style-type: none">• Three small communities within an area with population of 88,000• Subject to flooding, deforestation• Low employment, high poverty	

Benefits/business value:
<ul style="list-style-type: none">• Corporate Sustainability Report supports listing on <i>Dow Jones Sustainability Index</i>• Better informed local communities see company as reliable partner and resource for information• Third-party verification allows limited incidents of less popular actions (remove illegal dwellings)• Investment in community infrastructure and climate change (i.e., weather related) resilience facilitates production continuity during and after extreme events• Improved local economic conditions reduces dependency on future mining support

Case study no. 3: Water Management for Alumina Refining
Objective: Optimize water usage and wastewater treatment
Solution: Water treatment and systems at alumina and aluminum refineries

Methods/technical approach:	Standards/regulatory drivers:
<ul style="list-style-type: none">• Use on-site wastewater treatment to eliminate fuel use from waste transportation, and reuse treated water on site to reduce discharge into local waterways• Reduce freshwater drawdown• Improve recovery process to capture and reuse of caustic soda for beneficiation process• Create and use a water risk management tool that covers use and discharge• Limit accidental discharge by reinforcing mine tailing lagoons and using topography for waste	<ul style="list-style-type: none">• IFC 3: Resource Efficiency, IFC 1: Assessment and Management of Environmental and Social Risks and Impacts• ICMM 6, (10, reporting), Water Commitments 1–3• ASI Principle 7 water stewardship
	Locations: Brazil and Qatar
	
	<ul style="list-style-type: none">• Qatar: water-poor region• Qatar: energy-rich location• Brazil: susceptible to flooding• Brazil: sensitive local hydrology

Benefits/business value:
<ul style="list-style-type: none">• Improve control over input sourcing reduces need for freshwater• Reduce cost for water resources and treatment• Reduce cost for caustic soda (ca. 15% of total cash costs in refining process)• Proactive water risk management contains ecosystem threats during extreme events• Proactive water risk management and on-site treatment minimize infrastructure disruption• Water husbandry co-benefits local communities

Case study no. 4: Red Mud Management for Alumina Refining
Objective: Improve options for red mud storage and sequestration
Solution: Dry stacking method for storing bauxite-alumina refining residue

Methods/technical approach:	Standards/regulatory drivers:
<ul style="list-style-type: none">• New filter press technique reduces moisture content in red mud to 22% (standard moisture content for drum filter is 36%)• Caustic soda, alumina, water recovery/reuse• Denser red mud residue requires significantly smaller areas for storage and sequestration• Storage dams are drained from the bottom for further caustic soda and alumina recovery• Storage dams may be reforested after 5 years deposition	<ul style="list-style-type: none">• IFC 3: Resource Efficiency, IFC 1: Assessment and Management of Environmental and Social Risks and Impacts)• ICMM 6, (10, reporting)• ASI Principle 6 emissions, effluents, waste

Location: Brazil



- Three small communities within an area with population of 88,000
- Subject to flooding, deforestation
- Low employment, high poverty

Benefits/business value:

- Reduce operating costs by recovering additional water, caustic soda, and alumina
- Use dry stacking to reduce environmental risk from extreme weather, flooding, or leakage
- Smaller storage areas reduce need for new dams, footprint expansion, and logistical effort
- Reforestation efforts can be used or monetized for carbon offsets

Case study no. 5: Cost-Effective Clean Energy for Aluminum Smelting

Objective: Long-term fixed price clean energy supply for smelting

Solution: Purchase Agreement (PPA) for hydroelectric power


Methods/technical approach:

- Preliminary financial agreement between company as anchor customer and governmental agencies permits project development and financing
- Shared investment and concessions: publicly funded energy infrastructure in exchange for company-funded smelter, job creation guarantee, financial support for national park to offset lands lost to hydroelectric plant
- Multi-year energy supply contract guarantees offtake to amortize public investment and 40-year commitment for reduced energy pricing for smelting company

Standards/regulatory drivers:

- IFC 3: Resource Efficiency, IFC 1: Assessment and Management of Environmental and Social Risks and Impacts
- ICMM 6, (10, reporting)
- ASI Principle 5 greenhouse gas emissions

Location: Iceland



- Area population of 5000
- High environmental sensitivity
- Highly educated community

Benefits/business value:

- Use of long-term pricing agreement will produce 30% energy cost savings over other smelting operations
- Guaranteed uninterrupted power supply to smelter, accounting for 1/3 of hydroplant’s output
- Three-year window between signing of agreement and start of operations
- Co-financing through banks and lenders looking to expand their green finance portfolio
- National parklands constructed under agreement create carbon sequestration, environmental benefit, community recreation, and national good will

6.3 Strategy and benefits

UNDP-Guinea is now working with the Chamber of Mines on operationalizing their intention to adopt specific sustainable mining practices. This strategic momentum is timely because a landmark 2019 US Supreme Court decision in *Jam v. IFC* exposes the World Bank's liability when financing negligent projects and promises to add pressure from civilian advocates. As an example, a suit has already been brought by 13 Guinean communities against the IFC for its support of mining projects, thus highlighting the immediate effect of the court's decision. Coincidentally, only days later, three major French banks announced their financing for the largest bauxite mining operation on the planet in Guinea [42]. As pressures to address increasingly empowered stakeholders grow, new pathways for investing in environmental and community sustainability gain much-needed traction.

6.4 Developments toward sustainable mining since project completion

Coastal mangrove rice growing has been impacted by bauxite dust released during mining. As a first step in providing opportunities for mining companies to engage in meaningful climate adaptation activities, the GCF recently approved a proposal for "Enhancing the Resilience of Guinea's Coastal Rural Communities to Coastal Erosion Due to Climate Change" (see Section 4). This proposal, submitted by UNDP-Guinea and the Chamber of Mines, represents a milestone achievement in advancing Guinea's SDG agenda beyond mandated royalties. Specifically, the Chamber of Mines pledged mining company investment to implement a paradigm-shifting adaptation solution based on (a) design and adoption of an integrated coastal zone management plan; (b) a tailored combination of ecosystem-based adaptation activities, including mangrove restoration and infrastructure for coastal protection; and (c) promotion of climate-resilient livelihoods among rural communities as a buffer against climate change risk and as incentive to preserve the mangrove ecosystem.

7. Conclusions

The experience of this 6-month engagement offers replicable values:

- **Academia** has a valuable role to play by virtue of expertise (Widder and Pacioni), objectivity, ability to ask questions that others cannot due to expectations in their deliverables, and access to talented labor (i.e., graduate students).
- **Best practices can be shared and adapted**—the companies operating in Guinea should share best practices and adapt others from comparable situations to conserve resources, engage community, and support the environment.
- **Research is a shared value**—measuring environmental health, resources, flows, and community well-being is an opportunity for collaboration between universities and industry and will facilitate standards compliance.
- **Standards for sustainability**—consensus around international standards ensures social license to operate, improved process efficiencies, resource savings, and funding opportunities for projects with multiple beneficiaries.

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Conflict of interest

An evaluation of potential conflicts of interest that could influence the scientific work described herein, including but not limited to financial, personal, and/or commercial conflicts of interest, was completed for each author and co-author of this manuscript. No conflicts of interest were identified.

A. Appendices: Guinea’s bauxite mining operations

	Company name	Controlling interest	Guinea interest (%)	Location	Concession type
CBG	Compagnie des Bauxites de Guinée	USA, Australia, UK (51% Halco: Alcoa, Rio Tinto-Alcan, Dadco)	49	Boké Rgn	Bauxite, alumina
	a.k.a. Guinea Bauxite Company				
	also party to CBG/GAC joint agreement				Bauxite, alumina
Fria	RUSAL (using three separate operating cos)	Russia (48.1% of RUSAL is owned by En + Group	0		
	d.b.a. Alumina Company of Guinea			Fria Prf, Boké Rgn	Bauxite, alumina
CBK	d.b.a. Compagnie des Bauxites de Kindia			Kindia Prf/Rgn	Bauxite, Alumina
	a.k.a. Kindia Bauxite Company				
COBAD	d.b.a. Compagnie de Bauxiteet d’Aluminie de Diandian			Boké Rgn	Bauxite, alumina
	a.k.a. Dian Bauxite Company				

	Company name	Controlling interest	Guinea interest (%)	Location	Concession type
EGA	Emirates Global Aluminum	UAE	0	Boké Rgn	Bauxite, alumina, aluminum
GAC	<i>d.b.a.</i> Guinea Alumina Corp <i>f.k.a.</i> Global Alumina Corp				
CDM	China Henan International Mining Development Group	China (41% Chico, 51% Y'ngc'g C'l Elec, 8% Henan)	0	Boffa Prf, Boké Rgn	Bauxite, aluminum
CPI	China Power Investment Corporation <i>a.k.a.</i> CPI Boffa Alumina	China	0	Boffa Prf, Boké Rgn	Bauxite, alumina
CHALCO	Aluminum Corporation of China Ltd. <i>d.b.a.</i> Chalco Guinea Company <i>a.k.a.</i> Chalco Hong Kong Ltd.	China	0	Boffa Prf, Boké Rgn	Bauxite
SBG	Metalcorp Group B.V. <i>d.b.a.</i> Société des Bauxites de Guinée <i>a.k.a.</i> SBG Bauxite and Alumina NV <i>a.k.a.</i> Guinea Bauxite Corporation	The Netherlands (76.1% Metalcorp)	23.9	Kindia Rgn	Bauxite, alumina
SMB-WAP	Société Minière de Boké—Wining Port Afrique <i>a.k.a.</i> Boké Mining Company	China, Singapore, France (Shandong Weiqiao Al Pwr, Winning Ship'g, UMS)	10	Boké Rgn	Bauxite
SBDT	Societe des Bauxites de Dabola-Tougue	Iran (51% SBDT)	49	Dabola and Tougué Prfs	Bauxite, alumina
AMC	Société Alliance Mining Commodities Guinée <i>a.k.a.</i> Alliance Mining Commodities Ltd.	Australia (90% AMC)	10	Gaoaul Prf, Boké Rgn	Bauxite
	Pella Ventures Limited <i>d.b.a.</i> Alufer Mining <i>a.k.a.</i> Bel Air Mining	UK (85% Pella Ventures)	15	Boffa Prf, Boké Rgn	Bauxite
AMR	Alliance Minière Responsable <i>a.k.a.</i> Responsible Mining Alliance	France		Boké Rgn	Bauxite

	Company name	Controlling interest	Guinea interest (%)	Location	Concession type
	Jaguar Overseas	India (50% Dynamic Mining)	50	Boké Rgn	Bauxite
	<i>d.b.a.</i> Dynamic Mining				
	<i>a.k.a.</i> International Gulf ZFC				
IMD	International Mining Development	Ireland		Fria Prf, Boké Rgn	Bauxite, alumina
	<i>a.k.a.</i> Lissa Mining				

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