Mining and Quarrying Emissions: Iron, Copper, Bauxite, Rock, Sand and Coal

Matthew Jolleys[1,*] and Paul Duddy[1]
1) Hypervine Limited
*Email- matthew@hypervine.io

1. Introduction

The mining and quarrying sector is concerned with extracting minerals for the purpose of selling primary ores to end-users, such as construction companies and metals refineries, to create an industrial end product. These industries are estimated to be responsible for 4-7% of CO_2 emissions globally [1]. However, the sector is subject to a lack of reliable emissions monitoring, as most countries do not report mining emissions as part of their commitments under the United Nations Framework Convention on Climate Change (UNFCCC), a treaty to which all UN members are signatories. While the UNFCCC provides a level of emissions reporting requirements, many governments instead rely on end-users to report domestic consumption on their behalf, which likely results in significant underreporting at a national level.

Mineral extraction can be divided into two classes: fuel mineral extraction, which includes lignite, bituminous, sub-bituminous and anthracite coal mining; and non-fuel mineral extraction, which in this case focuses on iron, bauxite and copper ore mining. Mining of these ores represents the majority of global non-fuel mineral extraction.

The majority of emissions from non-fuel mineral extraction are produced by the stationary combustion of fuel by fixed and dynamic plant machinery on the extraction site, whereas emissions from fuel mineral mining are predominantly attributed to the escape of methane gas from the coal mine, with some emissions generated from fuel combustion (Table 1)[2].

Non-fuel mineral extraction is fairly concentrated in terms of geography. For example, Australia, Brazil, China, India and Russia are responsible for 80% of global iron ore production. Chile alone represents 32% of the global copper ore market, while Australia and Guinea comprise around two thirds of the global bauxite ore market. Countries with significant mining sectors are detailed below in Figure 1 and highlighted by their most significant mined commodity.

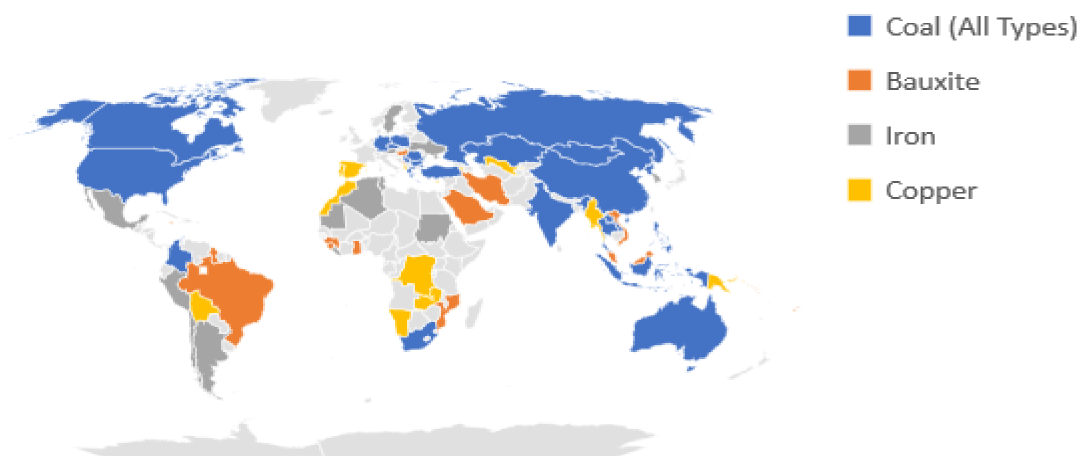

Figure 1 *Most significant mineral extraction activity by country.*

Facility-level data for emissions is essential to improve transparency and accountability within the sector. The current method for estimating emissions in the minerals extraction sector is to assume that all diesel bought by mining companies is burned, and therefore, to assign emissions on that basis. This is likely incorrect as companies are increasing the size of fuel stockpiles and therefore not burning all purchased fuel [3]. Furthermore, many countries simply do not have sector-assigned fuels sales data, and, in some countries, fuel is not bought in the same market in which it is consumed. Reliable reporting of emissions along supply chains is important, as these minerals are primary feed-in products to many industries, such as heavy manufacturing, construction and agriculture. Companies and countries will therefore require data on the emissivity of the primary products used to refine their own outputs in order to meet their Net Zero targets.

Table 1 *Description of scope of modeling activity*

Mineral	Emissions source	
	Mining, logistics and handling	**Fugitive methane**
Iron/Bauxite/Copper ores Rock quarrying (National Only) Sand quarrying (National Only)	✓	╳
Coal (Anthracite, Bituminous, Sub-bituminous and Lignite)	✓	✓

Here, we estimated emissions from mining and quarrying extraction on a statistical basis by taking production numbers at a national and facility level and applying specific mining and quarrying emission factors. These emission factors are based on the quality of ore, and geographically-relevant fuel mixing ratios where available, along with other characteristics of the facility such as the method of handling and types of machinery used.

2. Materials and Methods

Two main approaches were employed to provide emissions estimates for the mining and quarrying sector. Firstly, a number of reporting sources were used to obtain specific production statistics for the most significant coal, copper, iron and bauxite mining assets globally. Secondly, several datasets contributed to the development of a statistical model to estimate emissions at a national level for these mineral types, along with sand and rock. On-site refining was not covered in this sector but reported in the Climate TRACE heavy industry assessments.

2.1 Datasets

The following ground truth data were employed in estimates of mining and quarrying emissions. A summary of each is provided in Table 2 below.

2.1.1 Mine and quarry historical capacity data and locations from the US Geological Survey (USGS) Mineral Yearbook

This dataset is available at the link below:
https://www.usgs.gov/centers/national-minerals-information-center/commodity-statistics-and-information

The USGS Mineral Yearbook provides historical capacity data for global mineral extraction at mining and quarrying sites of global significance, based on production levels. The USGS yearbook is updated annually, with the 2022 version used for this work. Minerals of importance are defined according to their relevance for global economic development. Data is provided as the mass of material ore extracted from the earth in tonnes/kilotonnes. This information was used to estimate country-level production, then converted to emission estimates.

Additionally, for asset level emission estimates, the USGS provided very coarse location information for extraction sites. We identified the 500 highest-producing mines across our chosen minerals - 250 coal mines of varying grades, 100 iron ore mines, 100 copper mines, and 50 bauxite ore mines. For each of the 500 highest-producing mines, locations were identified in Google Earth imagery, with the USGS coordinates updated to reflect the actual asset locations.

These 500 assets were chosen due to their global significance to the mineral commodities trade, based on USGS capacity and production statistics. For coal, the identified assets represent only 1% of the global coal mining market, but over 50% of the total coal emissions. For non-fuel ores, these assets represent 70% of the global iron mining industry, 40% of copper mines and 67% of bauxite mines, while accounting for 80%, 70% and 72% of total emissions for each ore, respectively. This disparity is a result of the heavy bias of mining production in large scale operations, which are more profitable.

2.1.2 Observatory of Economic Complexity

Data from the Observatory of Economic Complexity (https://oec.world/) were used to understand the flow of trade, reported as dollar value, which we then converted to the volume of rock and sand imported and exported. This information was used to remove imported rock and sand from the national demand to better reflect country-level domestic usage.

2.1.3 UEPG Mineral Publication

The UEPG is the European Aggregates Industry association (https://uepg.eu/) which is responsible for the sand and rock mining industries in the EU27 (members of European Union), United Kingdom, and 10 additional countries on the continent. It produces a regular publication which includes annual data on total aggregate material production within member countries, supplementing the USGS data as an additional source for crushed rock and sand quarrying.

2.1.4 Global Energy Monitor Coal Mine Tracker

Global Energy Monitor’s Coal Mine Tracker (https://globalenergymonitor.org/) was used to retrieve a mixture of absolute and estimated locations for 250 coal mine assets. Additionally, this dataset provided a source of coal mine production information, along with methane emission factors based on mine depth which can be used to infer coal mine emissions. It is generally understood within the industry that methane emissions are driven by the depth of coal mines and the gasification of the grade of coal mined within the seam. Production data from this source were also used to identify mines of the greatest global significance.

2.1.5 Mining Data Online

Mining Data Online (MDO; https://miningdataonline.com) monitors the mining industry to provide information on mining projects at a global scale, including production data for primary extraction and derivative products. Their database includes coverage of 64% of the most significant non-fuel assets identified here (79 for copper, 72 for iron, and 10 for bauxite). These production statistics were combined with independent emission factors to derive estimates for CO_2 emissions resulting from the mining of these minerals. All reporting from MDO is performed on an annual basis, providing data for 2020 for all active assets represented within their database.

2.1.6 Additional sources

Where assets were not covered by any of the previous inventories, additional resources were used to define mining activity levels. These included the website Mining Technology (https://www.mining-technology.com), developed by GlobalData, to provide reporting and analysis of a range of mining sectors worldwide. Further sources for remaining assets included company annual reports, financial statements, press releases and newspaper and wider media reports (see Table S1). While a proportion of this data was available explicitly for 2020, not all assets were complemented with up-to-date or year-specific data. Therefore, in a limited number of instances, data for 2019 are provided, or annual-average production values established over the operational lifetime of certain assets are given where year-specific data were unavailable.

Table 2 *Summary of ground truth datasets*

Dataset Name	Measurement type	Usage	Geographic regions
USGS Minerals Yearbook	Tons/ore/year extracted	Acquiring historic data on minerals production, production sites, production capacity, ore quality	Global
Observatory of Economic Complexity	$USDs ore/year traded	Obtaining import and export statistics for minerals and related economic activity	Global
UEPG Mineral Publication	Tons/ore/year	Additional dataset for historic stone mineral production	EU27+UK+10 other member states
Global Energy Monitor Coal Mine Tracker	Locations of coal mines, ore extracted	Identifying coarse locations of coal mines, mining activity	Global (for mines over 3m tons per annum)
Mining Data Online	Locations of coal mines, ore extracted, processed outputs	Identifying coarse locations of coal mines, mining activity	Global (partial coverage)
Additional Sources	Ore extracted, extraction methodology	Providing additional validation data	Facility-specific

2.2 Models

This approach was developed in response to the lack of up-to-date and comprehensive production statistics across the global mining sector. The resulting model is based on the use of historical USGS national production data for each mineral type, which is subsequently forecast forward to 2021. An emission factor was then applied to this projected production value, based on the ore quality, fuel required to be burned to extract the mineral, and the type of extraction activity typically associated with the ore. These activities include methods such as truck and shovel extraction and dragline extraction, which uses larger plant machinery and often produces material at such a scale that it necessitates railway transport.

2.3 Methods

2.3.1 Geolocating the 500 assets

PlanetScope imagery and Google Earth Pro were used to identify and verify the locations of the 500 assets referenced in section 2.1.1, where accurate coordinates were not reported in associated datasets (Figure 2). For some sites where reported locations were imprecise or poorly defined, additional resources were required to verify exact locations, including written reports and ground-level photographs.

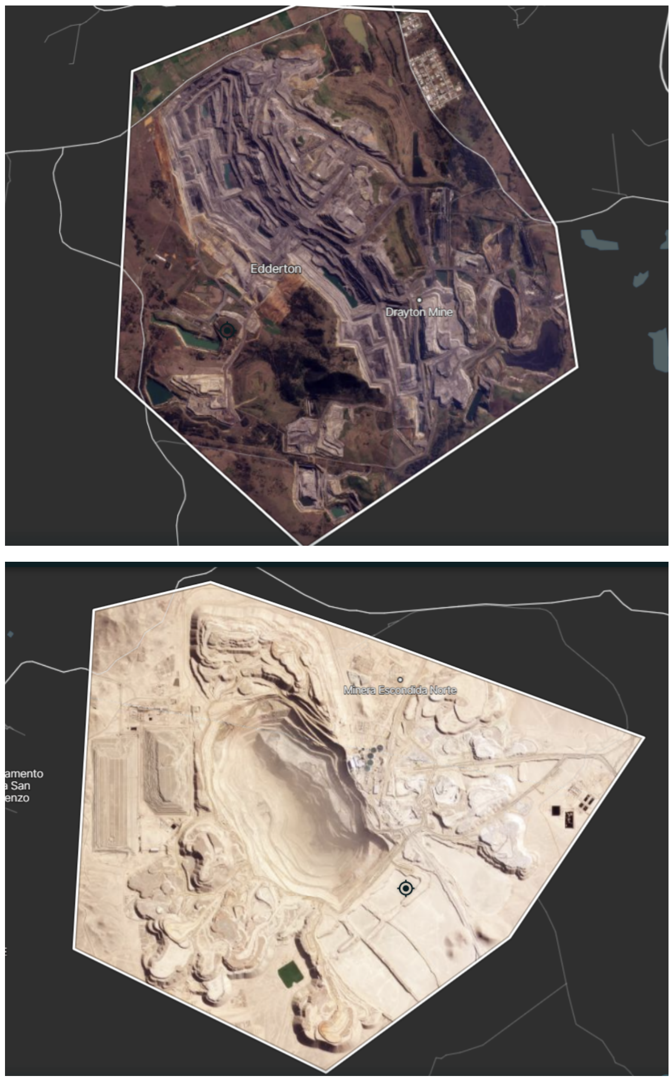

Figure 2 *Examples of mines that required geolocation verification.* ***Top****, Drayton Coal Mine, New South Wales, Australia.* ***Bottom****, Escondida Copper Mine, Atacama Desert Region, Chile.*

2.3.2 Statistical model for country-level emissions

Figure 3 provides a schematic representation of the stages involved in modeling emission estimates at a country level. The first step involved deriving national production statistics for each mineral, using a minimum of 10 years of data provided by agencies carrying out annual mineral commodities reviews and surveys, such as the USGS and UEPG, for the period of 2009-2018. This data was supplemented by related reporting of industry activity, imports, and exports. The mineral industry provides primary feedstock for a variety of other industries, including construction, agriculture, smelting, and metals refining. Consequently, analysis of these markets can be used to support reporting of extraction activity at a national level. Due to the absence of updated reports since 2018 for many nations, production data was extrapolated forward for more recent years to compensate for the lack of primary data. As a final step, mineral-specific emission factors were applied to derive CO_2 emission estimates for all mineral types, along with CH_4 for coal. Direct CO_2 emissions in the mining sector are driven by ore quality, and the proximity of an ore seam to the surface, which determines the amount of energy required in the process of extraction. This relationship was affected both by the mass of ore which must be extracted to derive a particular amount of the given mineral in accordance with its grade, and the techniques used to physically extract ore, as a function of the location, size and morphology of the mine itself. To determine emission factors for each country, asset-level factors (see section 2.3.3 below) were averaged after weighting according to the proportional contribution of each asset to national-level production.

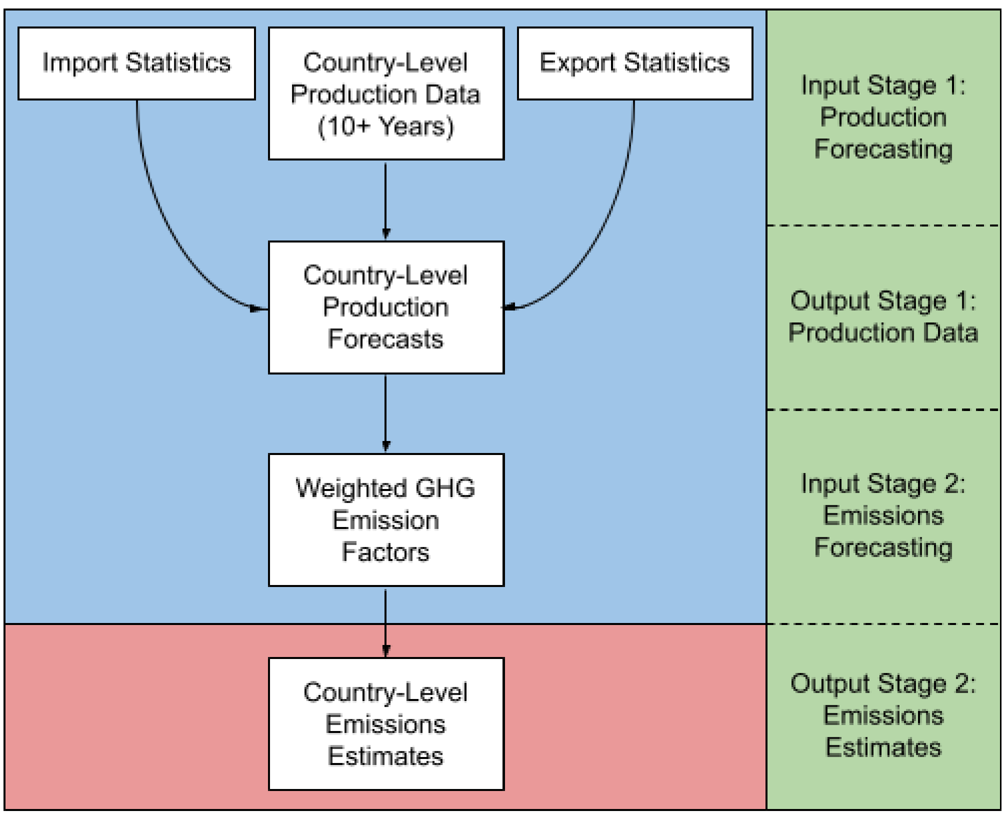

Figure 3 *Block diagram of emissions estimates model for national-level production.*

2.3.3 Asset-level emissions

As annual asset-level production data were widely available explicitly for 2020, emissions could be calculated directly by applying an emission factor to reported production values, without the need for projecting values from historical data. While emission factors were assigned for each facility, there was a degree of normalisation resulting from use of geographically-specific parameterisations such as fuel mixing ratios, or characterisation of mine properties including type (open-pit or underground) and extraction method (Table S1). Emissions were estimated for 2020 rather than 2021 due to a greater availability of production data for this year. However, these datasets will be revised as more up-to-date production data is made available going forward.

3. Discussion and future work

Current methods for assessing emissions at a national level in the mining sector are insufficient to facilitate accurate modeling of associated emissions. The approach developed here relies on certain assumptions, such as that all fuel purchased by mining companies is burned and derives emissions on this basis. Data required to calculate emission factors are not always consistently available for all nations, due to costs associated with providing the mechanisms for accurate reporting of these parameters. As a result, very few countries report stationary fuel combustion emissions for mining in any capacity. Despite such limitations, the methods applied here were able to provide global emissions estimates for all countries which engage in mining activities. These models also make limited use of internal company reporting data, consequently providing largely independent emission estimates.

Due to relying on third-party sources for production data, the inclusion of mining assets is dictated by the coverage of data providers, or the availability of data from alternative sources. Such sources have proved to be somewhat inconsistent, both in regard to the types of sources available and the metrics with which data are reported. The predominance of larger mining operations in reporting, across all these data providers, means it would be difficult to scale this approach to small mining activities. These assets are generally poorly represented in reporting due to their relative insignificance to the global minerals trade. It remains important to highlight that this model does represent the largest emitters, with the current data release for coal covering 1% of the world's coal mines but around 50% of global coal mining emissions. This concentration of global mineral production amongst the world's largest mines is evidenced across all mineral types, due to economies of scale making it more efficient to focus activity on large extraction sites rather than across multiple small ones. The low percentage coverage of total coal mining facilities is largely a result of China containing around 18,000 very small mines which have limited impact on mineral trade values.

Opportunities exist to improve the performance of this model, including by directly counting the number of machines operating in a mining area. This is currently averaged out in emissions factors based on the size of mine, with an assumption made on the typical number of machines operating per tonne of material extracted. The magnitude of improvement such quantification would provide is uncertain, as it is generally understood that the number and types of vehicles used on mines are broadly similar worldwide. However, such an approach could also improve understanding of the type of lading activity taking place on each mine, providing additional clarification on emissions sources. Efforts to develop machine-counting techniques are being developed in conjunction with researchers from Strathclyde University as part of an existing collaborative agreement, with further progress expected over the coming year and eventual plans to integrate this work with remote sensing of mining activity to produce more robust assessments of associated emissions.

Refinements to mining emissions estimates on the Climate TRACE platform are made on a continuous basis. Certain discrepancies have been identified amongst comparisons between country-level estimates for 2020 and corresponding cumulative estimates derived from asset-level data. Aggregated asset-level estimates sometimes exceed country-level estimates for certain countries and mineral types. This is likely to be a result of the use of more accurate production data for individual facilities, in comparison to a national level where more extensive averaging of input data and emission factors can introduce a negative bias in model outputs. We are working to address this issue and plan to make refinements and improvements to this approach, in particular to the implementation of country-level production data.

4. References

[1] Mineral Production to Soar as Demand for Clean Energy Increases, *World Bank* (https://www.worldbank.org/en/news/press-release/2020/05/11/mineral-production-to-soar-as-demand-for-clean-energy-increases)

[2] Yearbook of Global Climate Action 2018, *Marrakech Partnership* (https://unfccc.int/sites/default/files/resource/GCA_Yearbook2018_Annex04_Industry_Snapshot.pdf)

[3] Stockpiling and Sums Insured: Does your Construction Insurance still add up?, *Gallacher* (https://www.ajg.com/uk/news-and-insights/2022/april/stockpiling-and-sums-insured)

5. Supplementary material

Table S1 *Additional sources for mining activity data for asset level estimates.*

Mine	Country	Mineral	Source
Norilsk Complex	Russia	Copper	https://ar2020.nornickel.com/business-overview/operational-performance
Erdenet Ovoo Mine	Mongolia	Copper	https://mcc.mn/emc
Letpadaung Mine	Myanmar	Copper	https://www.brimonitor.org/case-studies/letpadaung-copper-mine-project/
Mopani Mine	Zambia	Copper	https://www.lusakatimes.com/2022/01/14/mopani-copper-mines-to-double-copper-output-annually-in-the-next-5-years/
Sarcheshmeh Complex	Iran	Copper	https://www.miningnewspro.com/En/News/125385/Sarcheshmeh-copper-Mine-and-Khatoon-Abad-Smelting-Factory-Production-Plans-Accompished
Frontier Mine	DRC	Copper	https://www.ergafrica.com/cobalt-copper-division/frontier/
Almalyk Mine	Uzbekistan	Copper	https://www.dobersek.com/en/copper/kupferschmelzofen-almalyk-republik-usbekistan/
Chambishi Operation	Zambia	Copper	https://www.spglobal.com/marketintelligence/en/news-insights/trending/8lxflyxbv606ugoup6xcbw2
Bystrinsky Mine	Russia	Copper	https://www.nornickel.com/business/assets/zabaykalsky-division/
Luanshya/Baluba Mine	Zambia	Copper	https://www.zccm-ih.com.zm/2019/12/16/cnmc-luanshya-copper-mines-extract-from-2019-annual-report/
Miduk Mine	Iran	Copper	https://mobinco.com/portfolio/stripping-and-mine-operations-miduk/
Keonjhar Complex	India	Iron	https://omcltd.in/Upload/Annual_Report_Documents/664ac3a193944deeabefb87e340335f0_20220521081636431.pdf
Marcona Mine	Peru	Iron	https://www.dipromin.com/noticias/shougang-hierro-peru-como-empezo-el-mercado-de-hierro/
Ingulets Mine	Ukraine	Iron	https://gmk.center/en/manufacturer/ingulets-gok-mining-and-processing-plant/
Noamundi Mine	India	Iron	https://www.dailypioneer.com/2021/state-editions/all-women-team-to-take-over-operations-of-noamundi-mines.html
Eruu Gol Mine	Mongolia	Iron	https://montsame.mn/en/read/237264

Sangan Mine	Iran	Iron	https://www.mesteel.com/countries/iran/Sangan_Iron_Ore_Mine.pdf
Bellavista Mine	Chile	Iron	https://www.bnamericas.com/en/news/santa-fe-minings-bellavista-iron-ore-operation-reaches-commercial-production
Chadormalu Mine	Iran	Iron	https://chadormalu.com/en-us/AboutMine
Jalal Abad Mine	Iran	Iron	https://fstco.com/en/projects/group/detail/Jalal-Abad-Low-Grade-Hematite-Iron-Ore-Processing-Plant--/53/view/
Nhan Co Mine Dak Nong	Vietnam	Bauxite	https://en.vietnamplus.vn/dak-nong-to-carry-out-bauxite-project/108297.vnp
Tan Rai Mine	Vietnam	Bauxite	https://en.vietnamplus.vn/na-delegation-checks-bauxite-projects-in-central-highlands/197625.vnp
Debele Mine	Guinea	Bauxite	https://www.enplusgroup.com/en/company/map/compagnie-des-bauxites-de-kindia-cbk/
Sierra Minerals Mine	Sierra Leone	Bauxite	https://vimetcobauxite.com/production-in-figure/
Friguia Mine	Guinea	Bauxite	https://www.africanminingnetwork.com/news/guinea-operations-to-resume-at-friguia-bauxite-mine/
Itamarati de Minas Mirai/ Poco de Caldas Mine Complex	Brazil	Bauxite	https://www.cba.com.br/RelatorioAnual2019/EN/
Nain Mine	Jamaica	Bauxite	https://jamaica-gleaner.com/article/business/20220429/jisco-mine-another-700-acres-bauxite-while-expanding-alpart
Kalimantan Mine	Indonesia	Bauxite	https://antam.com/downloads/annual-report-2020
Awaso Mine	Ghana	Bauxite	https://amaghanaonline.com/2022/03/21/a-wholly-new-ghanaian-consortium-takes-over-ghana-bauxite-company-from-bosai-minerals-group-from-china/
Clarendon Complex	Jamaica	Bauxite	https://jbi.org.jm/industry/
Torgayskoye/Krasno-Oktyabrskoye Mining Complexes	Kazakhstan	Bauxite	https://www.metalbulletin.com/Article/3783577/Non-ferrous-Metals/ERG-brings-13-mln-tpy-of-bauxite-on-stream-in-Kazakhstan.html
Ewarton/Manchester Mining Operation	Jamaica	Bauxite	https://www.enplusgroup.com/en/company/map/windalco/

West Rennell Islands Mine	Solomon Islands	Bauxite	https://pubs.usgs.gov/myb/vol3/2019/myb3-2019-solomon-islands.pdf
Lohardaga Mine Complex	India	Bauxite	https://lohardaga.nic.in/mines-and-minerals/
Niksic Mine	Montenegro	Bauxite	https://pubs.usgs.gov/myb/vol3/2019/myb3-2019-montenegro.pdf
Jajarm Mine	Iran	Bauxite	http://en.iranalumina.ir/Bauxite_2199.html
Teluk Ramunia/Pengerang Mine	Malaysia	Bauxite	https://www.statista.com/statistics/1131247/malaysia-bauxite-production/
Gadhsisa Complex	India	Bauxite	https://indianexpress.com/article/cities/ahmedabad/gmdcs-lignite-production-dips-after-closure-of-panandhro-mine-7264783/