Qualitative data envelopment assessment of different alumina refinery plants: the case of bauxite mining in West Kalimantan Province

Hendrik*1, A Fauzi1, Widiatmaka1, D T Suryaningtyas1 and F Firdiyono2
1IPB University, Bogor, Gedung Sekolah Pascasarjana Lantai II Kampus IPB Baranangsiang Bogor 16144
2Research center for Metallurgy and Materials-Indonesian Institute of Sciences, Gedung 470, Kawasan Puspiptek, Tangerang Selatan, Indonesia
*E-mail: hendrik_lee@apps.ipb.ac.id

Abstract. West Kalimantan is a bauxite-rich province with the world's sixth-largest bauxite reserve. However, Indonesia experienced a bauxite, alumina, and aluminum import vs. export deficit (2018-2020), with imports exceeding exports in value. Based on the calculation of qualitative data envelopment analysis, this case study provides a solution through benchmarking assessment to measure the relative performance of bauxite resource utilization for 12 alumina plants (DEA). This technique utilizes each provincial district’s alumina production plan data to characterize its production technology, which provides a better analysis of how the status of the refinery development plan provides efficiency of alumina refinery plant development according to bauxite allocation across several districts. To determine the benchmarking site, the qualitative DEA method compares the performance analysis of the Charnes, Cooper, and Rhodes (CCR) model for constant return to scale (CRS) and the Banker, Charnes, and Cooper (BCC) model for variable returns to scale (VRS). According to the findings of the scenario I, Kapuas, Kendawangan, and Tayan Hilir are efficient sites. Sungai Kunyit and Cempage Hulu are also benchmarking units in Scenario II. This study aided in the development of a sustainability assessment for the implementation of an alumina refinery development plan across districts in West Kalimantan province.

1. Introduction
Because aluminum is the most common metal element in the earth's crust (8.1%), it is quite common to find bauxite deposits of sufficient concentration to mine economically. Indonesia has the world's sixth-largest bauxite reserve, and in recent decades has witnessed the transformation of the bauxite mining industry in the global bauxite market [1]. These changes are primarily the result of resource nationalism, a policy that requires a company to invest in local industries via alumina refinery development plans. [2]. Researchers have described the impact of such policy in various ways; some are optimistic about the new mining project’s benefits to the local economies [3], while others are concerned about the negative impact on extraction of minerals from the ground, such as land disturbance [4], social concern [5]. Amid such discussion, current literature is replete with case studies of forcing industrial policy requirements in alumina plant sites. Although the progress of construction of alumina refinery facilities and mining town development index are comparable in that refinery technology and alumina refinery
plant sites, they differ in the efficiency of bauxite resource utilization of mining town and ownership structure.

Yet, despite the growing literature, existing studies tend to be situated in developed country contexts. As a result, in developing countries, issues in the countries such as the United States dominate the national policy theories used to compare and analyze “downstream processing” in the global south and global north [6]. As noted by Ostensson [7], many researchers apply the concept of transforming bauxite mining as if downstream processing from the ore or concentrate stage usually involves weight reduction (three quarters for bauxite/aluminum), so lower transport costs should be a strong incentive for further processing. As reported by Lèbre [8], The bottleneck of metal supply is associated with the environment, social, and governance issues that will impact the development of new mining projects, with bauxite having the highest risk of supply disruption. Downstream processing theories provide a rich discussion of how government must force firms to invest in local industries through industrial policy requirements.” Yet, few have sought to define the sustainable bauxite mining sector that the government can use and how “industrial policy requirement” effects can maximize the benefit of the mining operation and encourage sustainable bauxite mining. However, it is unclear how resource nationalism-driven policies shape the bauxite mining sector on a "global" scale, particularly in the case of developing countries that see it as an ongoing business risk.

To fill this gap, this paper focuses on bauxite mining in West Kalimantan, which has the most Mining Business Permits (IUP) in Indonesia with details of 80 Exploration IUPs and 38 Production Operations IUPs (Clean and Clear status), and where the government of Indonesia has mandated that bauxite cannot be exported and that an alumina refinery be built in the country. Alumina plants are very high capital costs ($US1.5Bn) that need to be sited as close as possible to vast resources of bauxite. Warburton [9] showed polarized ownership structure in which domestically owned companies dominate sub-sectors like bauxite, and most foreign investment was made up only 0.1 percent of gross domestic product (GDP) in 2012. Due to the global pandemic, the Indonesian government recently issued the Minister of Energy and Mineral Resources Decree No 104.K/HK.02/MEM.B/2021 establishing guidelines for imposing administrative fines for late construction of metal mineral refining facilities during the Corona Virus Disease 2019 (COVID-19) pandemic [10].

This case study seeks to explain the development of 12 alumina refinery plants to the index development town in mining town around West Kalimantan province. The paper considers the implication of the imposing alumina plant development policy requirement that will affect the efficiency of the development of new mining projects.

2. Methodology

This study uses descriptive analysis to obtain an inside view and interpretation of an alumina refinery plant, followed by the qualitative method using graphs and tables. Frontier Analyst Banxia software which belongs to data envelopment analysis (DEA) tools, was used to calculate the efficiency of alumina refinery plants. Qualitative DEA methodology used linear programming to measure the efficiency of input and output variables [11].

The Banker–Charnes–Cooper (BCC) DEA model was created by Banker, Charnes, and Cooper in 1984. On this basis, the Variable Returns to Scale (VRS) model, often known as the pure technical efficiency model, is developed. BCC DEA models are created by adding a constraint to dual models \( L_{CCR}^{id} \) and \( L_{CCR}^{od} \). The CCR DEA model can be used to estimate the efficiency score of any DMU using the formula below (Xi represents the input variables and Yr represents the output variables) [the formula for \( \min \frac{1}{g_k} \) refer to Charnes [12]].

\[
\min \frac{1}{g_k} = \sum_{i=1}^{m} v_i x_{ik} / \sum_{r=1}^{s} u_r y_{rk}
\]

Subject to


\[
\sum_{n=1}^{m} v_i x_{ik} \geq \sum_{r=1}^{s} u_r Y_{rk} \geq 1, j = 1, ..., n
\]

(2)

Qualitative DEA has several attractive features: it allows evaluation with multiple inputs and multi outputs. This exploratory study was carried out using a case study approach. The software used is DEA frontier. The analysis using the DEA program produced performance improvements from inefficient units [13].

Previous studies have based their criteria for selection on basic DEA models—both the CCR model for CRS and the BCC model for VRS. This model allows for comparisons of the technical efficiency of a bauxite mining stage to others within the same firm. A significant advantage of the constant returns scale (CRS) is that an increase input should generate a proportional increase of outputs. But, the choice of constant or variable returns to scale depends on the specific application. CRS is one of the most common procedures for comparisons of the performance of multiple large firms. Fuzzy DEA can be more appropriate in most other circumstances [14]. Numerous researchers have investigated the presence of both qualitative and quantitative factors [15]. Ordinary data is considered to be interesting, but experience showed that when money is scarce, policymakers place less emphasis on qualitative factors [16].

2.1. Variables and data collection

The alumina refinery plants identified by Indonesia's Ministry of Energy and Mineral Resources serve as samples in this study. The secondary data is obtained from the geoportal using purposeful sampling. The primary data is obtained from the interview with the experts. Joe [17] indicated some rules of thumb on the selecting the number of the inputs and outputs and their relation to the Decision-Making Units (DMU). Samples were analyzed for DEA as previously reported by Zhu [18]. The criteria for selection of DMU relation was divided into three categories: natural resources input, non-natural resource input, and one output to their DMU relation. In this case study, we employed bauxite as the natural resource input, fixed investment as the non-natural resource input, and village index development as the output. The following table 1 summarizes the corresponding input-output measures in this study.

| Table 1. Variables of inputs and outputs |
|-----------------------------------------|
| Inputs/output                          | Variable         | Units                     |
| Natural resource input                 | bauxite          | Million ton               |
| Non natural resource input             | Fixed investment | Million USD               |
| Output                                 | Town Development | Index                     |
| Input                                  | Target           | Percentage                |

Throughout the study, data was collected from a variety of sources at various points in time. Figure 1 depicts a group of locations knowns as DMU. The quantitative factors came from the database https://geoportal.esdm.go.id/minerba/. Furthermore, the alumina input materials were obtained from the https://www.minerba.esdm.go.id/. The qualitative factors were obtained from the status of development plan, while the ordinary data was explored from the https://kemenperin.go.id/. The index for town development (ITD) was investigated at https://idm.kemendesa.go.id/ which consists of Social Resilience Index, Economic Resilience Index and Environmental/Ecologist Resilience Index, and the completion schedule of alumina plant site was obtained from the database https://momi.minerba.esdm.go.id/public/. The legal basis for this ITD is Regulation of the Minister of Villages, Development of Disadvantaged Regions and Transmigration No. 2 of 2016 concerning the Index of Developing Villages [19]. This study was conducted from January to March of 2021.
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Figure 1. Location of alumina refinery development plan (source https://geoportal.esdm.go.id/minerba/)

This research will begin with an assessment of the sustainability rating of the alumina refinery requirement in 11 mining towns, namely: Kendawangan, Tayan Hilir, Cempaga Hulu, Sungai Kunyit, Matan Hilir utara, Toba, Meliau, Kapuas, Marau, and Gunung Kijang. The assessment is divided into three zones based on the availability of energy and mineral resources. Zones 1, 2, and 3 cover West Kalimantan, Central Kalimantan, and Riau, respectively, and were specifically identified as having the best bauxite potential by previous Dutch employees [20].

3. Results and Discussions

Because of the very high energy (+30-50MW of electricity) and capital cost of the alumina plant ($US1-1.5Bn), the alumina plants must have a very long working life. As a result, they must be located as close to large bauxite resources as possible, which they must control. At the same time, alumina is supplied globally due to the availability of relatively affordable alumina powder required for smelting. A deep-sea port (16m draft or larger) is required to enter the trade competitively unless one is extremely close to the smelter. The following table 2 illustrates the input and output values.

| Company                          | Location               | Bauxite Input | Investment | ITD      | Target |
|----------------------------------|------------------------|---------------|------------|----------|--------|
| PT WHWAR I                       | Kendawangan            | 4             | 2280       | 0.7315   | 100    |
| PT Indonesia Chemical Alumina    | Tayan Hilir            | 0.75          | 500        | 0.7174   | 100    |
| PT WHWAR II                      | Kendawangan            | 4             | 374        | 0.7315   | 90     |
| PT Parenggean Makmur Sejahtera   | Cempaga hulu           | 3             | 477        | 0.6871   | 21     |
| PT Borneo Alumina Indonesia      | Sungai Kunyit          | 3             | 773        | 0.8073   | 20     |
| PT Kalbar Bumi Perkasa           | Tayan Hilir            | 3.6           | 1400       | 0.7174   | 35     |
| PT Laman Mining                  | Matan hilir utara     | 2.8           | 900        | 0.7718   | 32     |
| PT Dinamika Sejahtera Mining     | Toba                   | 6.3           | 1129       | 0.6772   | 41     |
| PT Persada Pratama Cemerlang     | Meliau                 | 2.5           | 438        | 0.7764   | 42     |
| PT Quality Sukses Sejahtera      | Kapuas                 | 2.6           | 450        | 0.7094   | 40     |
Large land areas are required for alumina plant sites, partly as a buffer zone, but primarily for the permanent storage of red mud. 2300Ha would be required for 50-year storage at 6m depth. Best practices are mandatory of sustainable alumina plant sites. As a result, the environmental, social, and governance (ESG) criteria and concurrent technologies that led to the new mining project to avoid alumina supply disruption are deemed high risk. The Bayer Process, which is used to refine bauxite to smelting grade alumina (Al₂O₃), the precursor to aluminum, is referred to as "smelter grade alumina" in technology. The Bayer Process, on the other hand, produced an insoluble residue known as "red mud," which posed an environmental risk. As a result, various studies on land use, hydrology, and cultural aspects, as well as geotechnical works and an accurate assessment of logistics routes and methods, are required.

The qualitative DEA model, which is based on natural resource utilization orientation, is used to calculate 12 alumina refinery development plans in various regencies on Kalimantan Island, based on geography and infrastructure. Table 3 shows the corresponding outcome. Understanding the sustainability impact of the bauxite mine and transformation throughout its life cycle is a critical factor for bauxite companies to consider [5]. As a result, several mining towns that have experienced the development of an alumina refinery plant are evaluated using two scenarios: scenario I is without a target and scenario II is with a refinery plant target. The efficiency score for alumina after using DEA with the CRS model is based on the simple assumption that a proportional increase in input will result in a proportional increase in output.

Table 3. Efficiency score using scenario I.

| DMU                          | Location         | CCR  | BCC  | CCR  | BCC  |
|------------------------------|------------------|------|------|------|------|
| PT WHWAR I                   | Kendawangan      | 0.47 | 0.81 | 0.47 | 0.52 |
| PT Indonesia Chemical Aumina | Tayan Hilir      | 1    | 1    | 1    | 1    |
| PT WHWAR II                  | Kendawangan      | 0.98 | 1    | 0.98 | 1    |
| PT Parenggengan Makmur Sajehtera | Cempaga hulu     | 0.72 | 0.76 | 0.72 | 0.89 |
| PT Borneo Alumina Indonesia  | Sungai Kunyit    | 0.75 | 0.89 | 0.75 | 0.77 |
| PT Kalbar Bumi Berkasa       | Tayan Hilir      | 0.54 | 0.79 | 0.53 | 0.56 |
| PT Laman Mining              | Matan hilir utara| 0.76 | 0.86 | 0.76 | 0.78 |
| PT Dinamika Sajehtera Mining | Toba             | 0.3  | 0.75 | 0.31 | 0.38 |
| PT Persada Pratama Cemerlang | Meliau           | 0.89 | 1    | 0.89 | 1    |
| PT Quality Sukses Sajehtera  | Kapuas           | 1    | 1    | 0.88 | 1    |
| PT Sumber Bumi Marau         | Marau            | 0.67 | 0.67 | 0.67 | 0.87 |
| PT Bintan Alumina Indonesia  | Gunung Kijang    | 0.47 | 0.83 | 0.37 | 0.43 |

On the one hand, chemical grade alumina plants have been constructed in Tayan Hilir, Sanggau Regency, West Kalimantan Province, and Cempaga Hulu, East Kotawaringin Regency, Central Kalimantan Province. Because of its technology, Tayan Hilir town has become a peer or benchmark reference to Cempaga Hulu refinery plants with the input orientation. Tayan Hilir, where a government-owned enterprise has built a chemical grade alumina plant, is located on a navigable river that flows from Kapuas to the sea at Pontianak via PT Pelindo I and is thus considered West Kalimantan's primary source of bauxite [21]. Cempaga Hulu town has an efficiency score of 0.8 because a local owned company has built a chemical grade alumina plant that is located far from a port facility that can be used for shipping export alumina and import coal and consumable products. The alumina produced at this plant would be transported by land routes. More research into accurate assessment of land transport routes and methods, as well as preliminary studies proving the technical feasibility of a chosen alumina plant site, is required.
PT WHWAR, a foreign direct investment, on the other hand, had built a smelter grade alumina plant. The joint venture company is located near Kendawangan town port in Ketapang Regency, where it has been developed into bauxite industry areas that are relatively appealing to investors. Because it allows ship-loading of alumina to Panamax ships in water over 15 meters deep, the location has become a peer for other DMUs. Furthermore, Meliau town, Sanggau Regency, is an efficient place for alumina plant site due to its proximity to the Kijing Beach International Port, Mempawah Regency, which makes it relatively appealing to alumina plant site.

![Figure 2 Frontier plot](image)

Figure 2 depicts the concave frontier produced by the combination of CRS and output maximization. The ratio of the active input/output variables is represented by the X and Y axes. Each unit is plotted against this ratio, and a border is drawn to encircle the result. The higher the output, the lower the input/output ratio, and thus the efficient limit in plotted units. A light blue box denotes inefficient units. A straight line drawn from the unit to the origin identifies inefficient unit targets.

The solid line in Figure 2 depicts an efficient frontier, which means that all units in the line are efficient units. Only Tayan hilir town and Kapuas town (Sanggau Regency) are on the border in this case. The other location is a wasteful unit. Unit ICA (Tayan Hilir) and unit QSS are the closest units to unit PT Dinamika Sejahtera Mandiri (Toba) in terms of efficiency (Kapuas). The frontier plot exists only when two inputs and one output are active for maximizing output or when one input and two outputs are active for minimizing inputs. This plot's scaling mode must be constant return to scale (CRS). Further study of inefficient units is required to assess the accurate technical feasibility.

| DMU                        | Location               | CCR   | BCC   | CCR   | BCC   |
|----------------------------|------------------------|-------|-------|-------|-------|
| PT WHWAR I                 | Kendawangan            | 0.52  | 0.81  | 0.5   | 0.54  |
| PT Indonesia Chemical Aumina | Tayan Hilir            | 1     | 1     | 1     | 1     |
| PT WHWAR II                | Kendawangan            | 0.97  | 1     | 0.97  | 1     |
| PT Parenggean Makmur Sejahtera | Cempaga hulu          | 1     | 1     | 1     | 1     |
| PT Borneo Alumina Indonesia | Sungai Kanyit         | 1     | 1     | 1     | 1     |
| PT Kalbar Bumi Perkasa     | Tayan Hilir            | 0.67  | 0.82  | 0.67  | 0.77  |
| PT Laman Mining            | Matan hilir utara     | 0.88  | 0.89  | 0.88  | 0.97  |
| PT Dinamika Sejahtera Mining | Toba                  | 0.47  | 0.75  | 0.47  | 0.50  |
| PT Persada Pratama Cemerlang | Meliau               | 0.89  | 1     | 0.89  | 1     |
The Indonesian government has mandated that bauxite cannot be exported and that an alumina refinery be built in the country. As a result, it has established industrial policy requirements through the Minister of Energy and Mineral Resources' Decree No 104.K/HK.02/MEM.B/2021 [10]. Thus, the efficiency of the DMU can be estimated using the output/input ratio in Scenario II, where the percentage is measured relatively by year of expected completion plant, namely the progression of completion scores from 0 (non-existent) to 100 (exist).

To demonstrate the use of qualitative DEA, table 2 shows 12 units of analysis (DMU) with three inputs and one output from each location dimension. For each DMU unit, the table data is then processed using linear programming. The results of the analysis of efficiency scores equal to one (efficient unit) described in table 3 show that there are more units than are only used to display in scenarios without a target. The efficient unit is PT Borneo Alumina Indonesia, a state-owned enterprise located in Sungai Kunyit town, Sanggau Regency, where PT Pelindo II has built a Kijing Beach International port. This site will be used by PT Borneo Alumina Indonesia to export and import bauxite in connection with a planned 2Mtpa alumina plant 6 kilometres away. When the findings of this study are compared to those of other studies, it is obvious that the presence of mining in a region can accelerate regional development [22]. Additional studies, such as corporate sustainability responsibility (CSR), will be required to develop a full picture of the synergy of mining town development among bauxite mining companies and local governments.

4. Conclusions
The goal of this study was to compare the sustainability of 12 alumina refinery plants to the sustainability development index of bauxite mining towns in West Kalimantan province. The second goal of this study was to look into the effects of imposing alumina plant development policy requirements on bauxite resources and environmental management of new mining projects in West Kalimantan province, where the Indonesian government has mandated that bauxite cannot be exported. The investigation of qualitative DEA scenarios I (mining town development index) and II (progress of construction of alumina refinery facilities and mining town development index) concerning the efficiency of bauxite resource utilization, technology, and ownership structure revealed that an alumina refinery plant must be built integrated with the mining towns, with only three locations, namely Kapuas, Kendawangan, and Tayan Hilir, owned by local enterprises, joint venture and government entities, respectively. When using a scenario I, those sites are deemed efficient. The alumina plant locations were important because it has a very high capital cost and its plants must be integrated as close to a large bauxite resource as possible, a deep-water port (16m draft or more), and extensive areas of land for the permanent storage of redmud. In addition to scenario I, the assessment using scenario II revealed that another mining town, namely Sungai Kunyit, PT Borneo Alumina Indonesia, a subsidiary of state-owned enterprise PT Inalum, and Cempaga Hulu, PT Parenggean Makmur Sejahtera, a local enterprise, are considered to be an efficient site to be integrated with the alumina plant. According to the findings of this study, an alumina refinery plant contributed to the long-term development of mining towns. However, a future study could assess the long-term effects of the multiplier effect of alumina refinery plant development because the integration of bauxite mining with alumina refinery plants is a government mandate and a requirement for a sustainable bauxite mining industry.

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