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Article

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Economic Strategies and Efficiency of Power Plants in Indonesia to Achieve Net Zero Emissions

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ABSTRACT

Indonesia is the fourth most populous country in the world. As a developing country, Indonesia needs electricity to boost its economy. Indonesia's efforts to achieve Net Zero Emission (NZE) will have difficulty achieving this goal because fossil fuels contribute 85% of its electricity production. This study aims to measure the operational variables of CFPPs, and CO2 is used to measure efficiency to help reduce carbon gas emissions. In addition, this study attempts to analyze the factors that make CFPPs less economically profitable. Data Envelopment Analysis (DEA) and Malmquist Productivity Index (MPI) techniques are used to measure efficiency. The results are 23% of CFPPs are in an efficient condition. While the rest are in an inefficient condition, in the future the CFPPs can be optimized by benchmarking against their peers and increasing the target of increasingly efficient CFPPs in Indonesia. CFPPs that are close to coal mines have relatively higher operational costs but have lower CO2 emissions than CFPPs located near economic centers. Government policies are needed in efforts to encourage cheap operational costs but with low CO2 emissions as well.

Keywords: CO2, Coal-Fired Power Plants, Data Envelopment Analysis, Greenhouse Gases
JEL Classifications: Q54, Q58, Q58

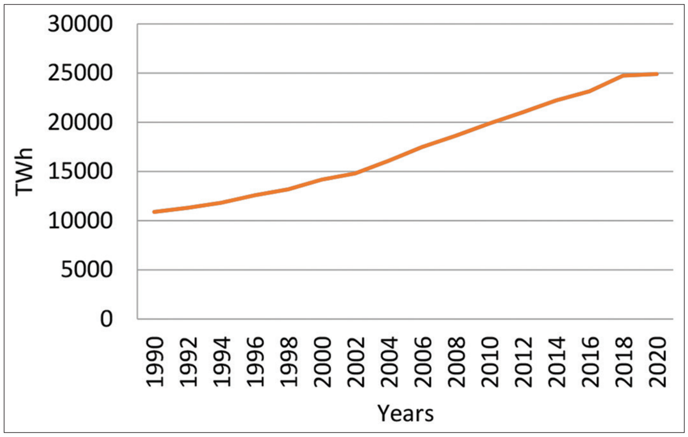
1. INTRODUCTION

Electricity has emerged as a key player in driving the global economy, as advancements in technology have made it essential for nearly all human activities. It serves as the fundamental energy source for various sectors, including corporate offices, industries, hospitality, healthcare, manufacturing, and even domestic households. The importance of electricity has only increased in contemporary society, especially due to technological innovations that rely heavily on electric power, such as electric cars and heat pumps. The electric industry is crucial not only for powering the global economy but also for driving the worldwide shift towards sustainability (Pacala & Socolow, 2004).

The illustration in Figure 1 reveals a consistent surge in global electrical demand spanning three decades from 1990 to 2020. Starting at 10,894 TWh in 1990, the electrical consumption escalated to 35,027.3 TWh by the year 2020. This equates to a 230% rise in consumption over the initial figure from 1990 to 2020. Although this uptrend in electricity usage has been noteworthy over these years, there was a noticeable plateau in the growth rate between 2018 and 2020, showing a less robust increase compared to other periods. Despite this brief phase of slower growth, the year 2020 still marked the apex of electrical consumption in the last 30 years. Forecasts for 2022 suggest a 2.4% uptick in consumption, following a 6% increment in the prior year. This aligns with the average growth trajectory over the past five years, even accounting for the previous periods of growth stagnation.

Coal stands as the primary fuel for electricity generation globally. According to the International Energy Agency's 2022 report, coal was responsible for 9,914,448 GWh of electricity in the year

Figure 1: Global electricity consumption (1990-2020)



2020. Previously, in 2018, coal-powered electricity saw a peak at 10,252,156 GWh before experiencing a decrease that continued through 2020, leaving a difference of roughly 700,000 GWh. Coal continues to be the leading source for electric power production around the world, primarily due to its cost-effectiveness and continuous operating capability. Although there has been some steady advancement in the adoption of clean energy, fossil fuels, namely oil and natural gas, continue to make up over 80% of worldwide energy consumption. Additionally, coal remains the primary source for approximately 50% of electricity production.

CFPPs that use coal as fuel release large amounts of CO2 into the atmosphere. The process of burning coal produces CO2 as a byproduct, which is the main greenhouse gas that contributes to global warming. Apart from CO2, this combustion also releases other dangerous gases such as sulphur dioxide (SO2) and nitrogen oxide (NOx), which contribute to air pollution and acid rain. High CO2 emissions from CFPPs contribute significantly to climate change. CO2 is a greenhouse gas that plays a role in increasing global temperatures, leading to changes in weather patterns, increased frequency, and intensity of extreme weather events, rising sea levels, and other adverse effects on the environment (Peng et al., 2018).

While energy use continues to rely heavily on fossil fuels, the resulting environmental impact poses a significant problem. Climate change, driven by global warming, is a pressing issue worldwide. It is characterized by an increase in global average temperatures across the atmosphere, oceans, and land. Various factors, such as industrial developments, business activities, and even natural disasters, contribute to this rise in temperatures. The primary cause of this change is an increase in greenhouse gases, notably carbon dioxide (CO2). Addressing this environmental challenge necessitates international collaboration between developed and developing countries, along with innovations in green technology (Sueyoshi and Goto, 2021). Growing economic activity and international trade have led to increased electricity demand, which contributes to environmental problems (Sari Saudi et al., 2024).

Electricity, which is a primary need that affects the lives of many people, is one of the drivers of the community's economy. Economically, Indonesia's limited ability to increase electricity production will hamper efforts to improve the business environment that can encourage investment growth. Electricity is a basic need for competitiveness because it plays a key role in increasing efficiency and productivity. Sambodo (2009) and Adam et al., n.d. (2016).

Infrastructure growth outside Java is slower than in Java, possibly due to limited electricity supply. The significant difference in electricity availability between Java and outside Java makes it difficult for outside Java to encourage its development. In addition, the low availability of electricity outside Java hampers government efforts to encourage investment and business. This is because electricity is one of the key factors in facilitating, encouraging and stimulating investment, business activities and various other socio-economic activities. (Adam et al., n.d., 2016) Indonesia, as a developing country, is witnessing an annual increase in electricity consumption. Home to the world's fourth-largest population, Indonesia faces the challenge of satisfying its citizens' growing electricity demands. With population growth, economic expansion, and the rise in various activities requiring electricity, the demand for electrical energy is set to escalate. This situation is particularly challenging given that over 85% of Indonesia's power generation relies on fossil fuels.

Following the Paris Conference of Parties 21, Indonesia has set a target to reduce carbon emissions by up to 41% by 2030. By 2060, the goal is to achieve net zero emissions (NZE), where the amount of carbon released does not exceed the earth's capacity to absorb it. Many countries are adopting low-carbon economic development policies to address increasing environmental pollution and the rising energy demand. Carbon trading is a specific policy aimed at reducing CO2 emissions and creating a beneficial link between China's carbon trading system and its shift towards a low-carbon economy (Wang et al., 2019).

This research aims to measure the operational variables of CFPPS and CO2 used to measure efficiency to help reduce carbon gas emissions. In addition, this study attempts to analyse the factors that make CFPPS economically less profitable. With this study, it is hoped that there will be an economic strategy that can help developing countries to continue to play an active role in climate change problems while maintaining the macro economy in their country.

2. LITERATURE REVIEW

Company performance refers to the degree of success in which the management effectively oversees the company, as measured by indicators of accomplishment that contribute to the attainment of predetermined objectives (Arnaboldi et al., 2015). The company strives to achieve company performance by establishing standardized indicators to measure the level of achievement. Company performance is determined by the profitability of an organization, which allows it to establish dominance in the industry. To analyse the extent to which a firm has achieved its goals and to enhance future performance, it is imperative to measure the organization's performance (Simpson and Simpson, 2022).

Efficiency is the proportion of the achieved production to the anticipated standard output. Efficiency is a quantification of the effective and ineffective utilization of resources in the pursuit of objectives (Charnes et al., 1978). Efficiency refers to the degree to which objectives can be accomplished with the finite resources at hand (Jaraiťe and Di Maria, 2012).

Data Envelopment Analysis (DEA) is a non-parametric technique employed to assess efficiency by optimizing the utilization of resources (input) to optimize the desired outcomes or expected output (Blum, 2015). The concept of Data Envelopment Analysis (DEA) was initially proposed by Cooper in 1978. It is represented by a formula resembling the following equation:

$$Max\ hj = \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}}$$

Data Envelopment Analysis (DEA) is frequently employed to assess the technical effectiveness of a Decision-Making Unit (DMU). The DMU, or Data Management Unit, is an organizational entity comprised of units that have the responsibility of transforming input resources into output. The application of DEA involves two models, namely Constant Return to Scale (CRS) and Variable Return to Scale (VRS), which are the most widely recognized approaches in the DEA method (Bongo et al., 2018a).

The CRS model postulates that the proportion between incremental input and output remains constant. In the VRS model, the ratio of new input to output is not equal. This research employs the VRS assumption, which posits that not all DMUs (Decision Making Units) are operating at an optimal level of efficiency.

The DEA Variable Return to Scale (VRS) model was discovered by Banker, Charnes, Cooper (BCC) (Cooper et al., 2006). In the VRS Assumption model, the ratio between the addition of input and output is not the same. This means that the addition of input by x times can be smaller or larger than x times (1) (2) There are 2 approaches in the BCC model (Bongo et al., 2018b). Another assumption is that the conditions at the DMU are different or not operating optimally. This model was discovered based on the CRS model which is still guided by the DEA mathematical model as an equation that measures the level of efficiency. The calculation of DEA VRS can be seen from the following formula:

$$\sum_n \lambda_n = 1$$

There is a difference between the CRS and VRS models with the addition of connectivity constraints (convexity constraints) in VRS which causes the efficiency value obtained by the VRS model to be higher than CRS. The use of the CRS model, where the DMU is not actually functioning optimally, results in the Technical Efficiency (TE) measure being defeated by Scale Efficiency (SE). Thus, the TE value in the CRS model (TEcrs) can be broken down into 2 components. These components are Pure Technical Efficiency (TEvrs) and Scale Efficiency (SE) (Li et al., 2022). Scale efficiency can be formulated as follows:

$$Scale\ Efficiency = \frac{TEcrs}{TEvrs}$$

The result of the calculation of scale efficiency produces a number one, so it can be concluded that the DMU is at an efficient point. Meanwhile, if TEvrs is greater than the SE value, then the increase or decrease in efficiency is caused by the pure technical efficiency value. Meanwhile, if the TEcrs value is greater than the SE value, then the change in efficiency is caused by the technical efficiency value.

The DEA method is categorized into two orientations: input orientation and output orientation. Input orientation in DEA involves the optimization of resource utilization to achieve a specific output. Output orientation is to optimize output outcomes using the available inputs or resources. This research adopts a results-oriented approach to maximize the desired output while also acknowledging that undesired output may occur as a side consequence of production. Efforts are made to limit the distribution of such unpleasant output.

The productivity index was introduced by an economist and statistician named Sten Malmquist in 1953. Sten Malmquist proposed a quantity index to be used in consumption analysis based on ratios in the distance function (Coelli et al., 1998). Along with the development of the era, Caves and his friends adopted Malmquist's idea to be applied to production analysis using the language he popularized called the Malmquist Productivity Index (MPI) which can be used to analyze productivity based on the distance function. The Malmquist index shows changes in productivity that occur in each entity or DMU from one period to the next. MPI can use catch-up effect measurements that show the level of relative efficiency change between periods (Thrall, 2000). MPI is used to obtain changes in Total Factor Productivity (TFP). TFP has the following basic formula:

$$TFP = M^{t,t+1}\left(X^{t+1}, Y^{t+1}, X^{t}, Y^{t}\right) = \left[\frac{D_c^t\left(X^{t+1}, Y^{t+1}\right)}{D_c^t\left(X^t, Y^t\right)} x \frac{D_c^{t+1}\left(X^{t+1}, Y^{t+1}\right)}{D_c^{t+1}\left(X^t, Y^t\right)}\right]^{\frac{1}{2}}$$

In practical terms, the unpleasant output model consists of three categories of variables: input, desired output (also known as good output), and undesirable output (sometimes referred to as bad output). Undesirable output is an incidental result of the generation of desired output (Kao and Hwang, 2021). The power generation sector is intricately linked to the production of undesirable byproducts, such as waste generated from the combustion of resources.

3. RESEARCH METHOD

This study is a quantitative optimization research aimed at measuring the performance of coal-fired power plants (CFPPs) located throughout Indonesia using Data Envelopment Analysis, particularly in relation to CO2 emissions, and linking it to solutions for achieving Net Zero Emissions in Indonesia.

This research uses the DEA method to measure the operational and environmental performance efficiency of CFPPs using input oriented. The input-oriented DEA model aims to reduce the amount of input at the output level. In determining variables, it is necessary to identify variables and group variables into input and output. Identify what variables play an important role in calculating efficiency and productivity at DMU. Adjustments to the selection must identify the objectives of the CFPPs to help operational performance run optimally. The next stage is the stage of grouping variables that have been identified into groups of input variables or output variables. The following is the data used as grouped variables in determining the core variables of CFPPS operational performance and environmental performance, more in-depth research is needed by making a table of the use of variables in several studies which have many citations and are still relevant to research conditions on the efficiency of CFPPs performance in Indonesia. The variables used are as in Table 1.

After measuring performance efficiency using DEA, proceed with calculating performance productivity using the Malmquist Productivity Index method. MPI model calculations can measure the productivity of an entity or DMU with a time comparison (Chen et al., 2023). The MPI calculation for the time from 2018-2022 was carried out to calculate changes in productivity at CFPPs in Indonesia by considering 5 components. The first calculation in this model compares pure technical efficiency (PTECH) with scaled efficiency (SECH) to obtain changes in operating efficiency values (EFFCH). Next, it is carried out to assess changes in operational efficiency (EFFCH) in performance management. Apart from that, the component that needs to be calculated is the technological or technical change (TECHCH) used by the CFPPS to produce electricity. After getting the values for the two components, the next step is to compare the two components to get the total change in productivity factor (TFP). The following is the formula for the five components in the MPI calculation:

Efficiency Change (EFFCH)

$$EFFCH = \frac{D_c^t\left(X^{t+1},Y^{t+1}\right)}{D_c^t\left(X^t,Y^t\right)}$$

Pure Technological Change (PTECH)

$$PTECH = \frac{D_v^{t+1}\left(X^{t+1},Y^{t+1}\right)}{D_v^t\left(X^t,Y^t\right)}$$

Table 1: Research variables

Variables	Information
X1	Installed Capacity
X2	Coal-Fired Consumption
X3	Operation Cost
Y^D 1	Electricity Generated
Y^u 1	CO_2
Y^u 2	NOx
Y^u 3	SO2
Y^u 4	Particulate
Y^u 5	Hg (Mercury)

Technical/Technological Change (TECHCH)

$$TECHCH = [\frac{D_c^t\left(X^{t+1},Y^{t+1}\right)}{D_c^{t+1}\left(X^{t+1},Y^{t+1}\right) D_c^t\left(X^t,Y^t\right)} \; x \; \frac{D_c^t\left(X^t,Y^t\right)}{D_c^{t+1}\left(X^t,Y^t\right)}]^{\frac{1}{2}}$$

Scale Efficiency Change (SECH)

$$SECH = \frac{SE^{t+1}\left(X^{t+1},Y^{t+1}\right)}{SE^t\left(X^t,Y^t\right)}$$

Total Factor Productivity Change

$$TFP = [\frac{D_c^t\left(X^{t+1},Y^{t+1}\right)}{D_c^t\left(X^t,Y^t\right)} \; x \; \frac{D_c^{t+1}\left(X^{t+1},Y^{t+1}\right)}{D_c^{t+1}\left(X^t,Y^t\right)}]^{\frac{1}{2}}$$

Sensitivity analysis is used to determine the sensitivity level of the amount of increase or decrease in the improvement targets that have been made to performance optimization, so that later the differences between before and after the target changes will be known. So, it can be said that this analysis is useful for knowing the level of variable optimization.

The analysis is carried out by explaining the results of efficiency and productivity measurement calculations. At this stage, we also pay attention to theoretical views on data processing that has been carried out previously. The results of data processing will show which variables are inefficient and have low productivity values so that they can become targets for improvement for the CFPPs.

4. RESULTS AND DISCUSSION

4.1. Efficiency Scale

The CRS measurement results will be compared with VRS which produces an efficiency scale. Calculation of the efficiency scale will produce a Decreasing Return to Scale (DRS), Constant Return to Scale (CRS), and Increasing Return to Scale (IRS) scale. The DRS score states that the proportion of increase in input is smaller than the increase in output. Meanwhile, the IRS Score shows that the proportion of input increase is greater than output increase. Efficiency will run optimally when the score is on the CRS value which shows the proportion of increased input proportional to increased output. The results of the efficiency scale calculation can be concluded as in Table 2 which shows the results of the proportion of CFPPs efficiency scales in Indonesia.

Table 2: CFPPs efficiency scale in Indonesia

YEARS	Efficiency Scale		
	DRS	CRS	IRS
2019	10	12	83
2020	9	8	88
2021	8	9	88
2022	5	8	92
Total	32	37	351
Percentage	8%	9%	84%

Based on Table 2, 8% have a decrease in input and only 9% have an efficient SE value. The remaining 84% of CFPPs have a greater proportion of input increase than output increase (IRS). Almost all CFPPs have inefficient scale values. In 2019 there were 83 provincial CFPPs operating on the IRS scale. The following year there was an increase to 88 CFPPs on the IRS scale. In 2021, 88 CFPPs will still have an inefficient efficiency scale. In 2022, this will increase to 92 CFPPs with inefficient efficiency scales. On the other hand, in CFPPs conditions, which are at a constant value, the increase in input and output (CRS) experiences changes in the amount every year. In 2019 there were 12 CFPPs with optimal efficiency scale. Furthermore, in 2020 the number of CFPPs decreased to 8 which had a CRS rating. In 2021 the number will increase slightly to 9 CFPPS operating on the CRS scale. In 2022 there will be 8 CFPPS operating on the CRS scale. For DRS scale or scale inefficiency caused by the proportion of increased input being smaller than output. From the analysis above, it is known that the efficiency scale values for CFPPs in Indonesia are mostly in increasing return to scale (IRS) conditions with a high percentage of 83%. This condition can be interpreted as meaning that the proportion of increase in input is greater than the increase in output. From Table 2 it can also be seen that the constant return to scale (CRS) scale value is 9%. This value can be interpreted as meaning that 9% of CFPPs in Indonesia are in a stable efficiency scale condition. The previous explanation states that almost all CFPPs experience scale inefficiencies. In 2019-2022 the number of CFPPs in Indonesia operating on the CRS scale is very small and the majority are on the IRS scale. This causes the appropriate efficiency calculation assumption in this research to be the VRS assumption (Cooper and Rhodes, n.d.).

4.2. Productivity Measurement using MPI

Productivity measurements from CFPPS Indonesia use MAXDEA software for the Malmquist Productivity Index (MPI) model. Measurements were carried out over 4 years starting from 2019-2022. The resulting value is the TFP or Total Factor Productivity value which is decomposed into 4 other values, namely EFFCH and TECH.

Productivity in this research uses the Malmquist Productivity Index approach which displays the Total Factor Productivity (TFP) value. TFP is the value of changes in productivity over time. The TFP value can be decomposed into several other values, namely Efficiency Change (EFFCH) and Technical/Technological Change (TECH).

TFP will express an increase in productivity when the value is above 1, while it will express a decrease in productivity when the value of TFP is less than one. Stagnation will occur when the TFP score from CFPPS in Indonesia is perfect. Changes in productivity at CFPPS in Indonesia can be analyzed through the TFP Score.

Changes in the Total Factor Productivity (TFP) value will be presented in the form of a comparative graph of changes in productivity in 2019-2020, 2020-2021 and 2021-2022. The graph shown is the Ten CFPPS with the highest productivity. Changes in the TFP value, which expresses the value of productivity in 2019-2020, can be seen in Figure 2.

In Figure 2 the highest increase in productivity in 2019-2020 was CFPPs Bolok 02 with a value of 1.7. Meanwhile, the lowest productivity is CFPPs Pacitan 02 with a value of 0.12. Changes in the TFP value, which expresses the value of productivity in 2020-2021, can be seen in Figure 3.

In Figure 3 the highest increase in productivity in 2020-2021 was CFPPS Bukit Asam 03 with a value of 1.7. Meanwhile, the lowest productivity is CFPPS Bolok 01 with a value of 0.55. Changes in the TFP value, which expresses the value of productivity in 2021-2022, can be seen in Figure 4.

In Figure 4 the highest increase in productivity in 2021-2022 is CFPPS Rembang 01 with a value of 1.7. Meanwhile, the lowest productivity is CFPPS Bukit Asam 03 with a value of 0.07. In terms of changes in productivity in 2020-2021 and 2021-2022, CFPPS Bukit Asam 03 experienced significant changes, after being the highest productive in 2020-2021, it turned out that in 2021-2022 it became the CFPPS that experienced the lowest productivity.

In 2022 there will be 26 CFPPs that will be in efficient condition. Efficient conditions are stated when the value of Technical Efficiency VRS (TEvrs) is one. Likewise, when the TEvrs value is below one, the condition of the CFPPS needs to be improved so that it is optimal, this can be seen in Table 3.

A total of 26 CFPPs or 23% of CFPPs are in efficient condition, the rest are in inefficient condition. With this minimal amount, it

Figure 2: Changes in productivity in 2019-2020

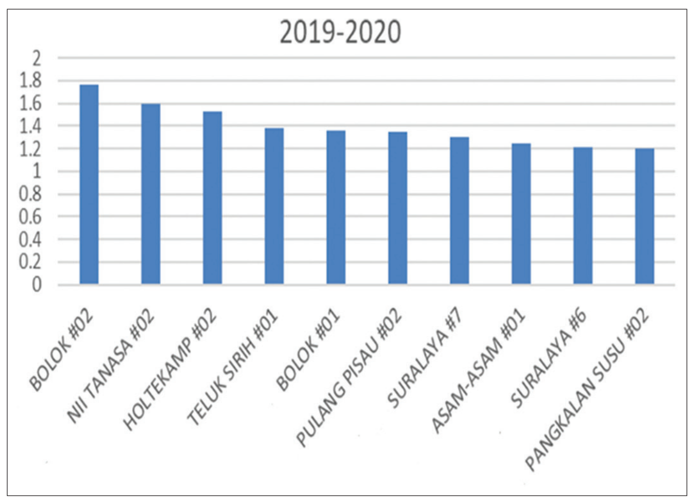
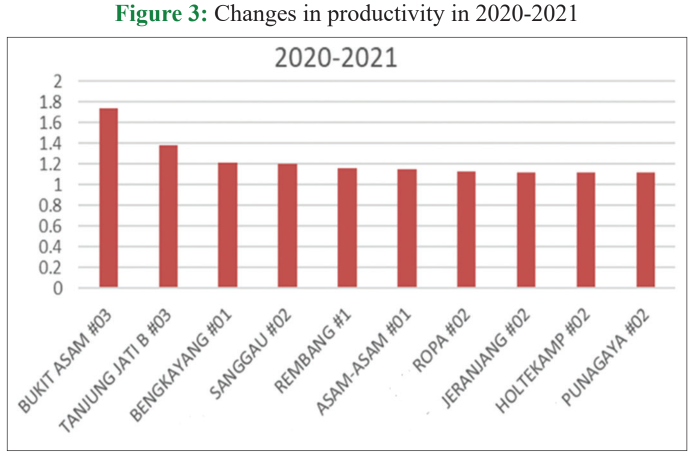


Figure 3: Changes in productivity in 2020-2021



is necessary to evaluate improvements for CFPPs in Indonesia so that they are in an efficient condition in the future. In this research, improvements were made according to the variables used by projecting the optimal values in the projection. DEA processing results also provide peers for CFPPs that are not yet efficient so they can benchmark against CFPPs that are already efficient.

A total of 74 CFPPs received projections for each variable, both input and output, to be optimal in the future. CFPPS Pelabuhan Ratu 03 is the CFPPS with the lowest efficiency score among the others. This means that this CFPPS requires more repairs compared to other CFPPs due to excessive use of resources and minimal production (Cooper et al., 2007).

4.3. Efficiency of Operational Costs of CFPPs

Based on 105 CFPPs studied in Indonesia, the largest operational costs in a year are Paiton #09 and Adipala #01 with operational costs of 1.605M USD and 1.501M USD. This is a reasonable thing because the CFPPS has a capacity of 660MW. However, this condition is not ideal because several CFPPs with larger capacities have operational costs that are not as large as the two CFPPs. This condition can be seen in the Table 4 and complete research data can be found in the appendix.

The operational costs for each electrical energy produced by each CFPPS have different results, with an average of 0.19 USD/kWh. The smaller the operational costs required to produce electricity, the more profitable the CFPPS will be. The conditions of the 10 largest CFPPs can be seen in Table 5.

The highest cost is in Teluk Berau #02 and Sumbawa Barat #1. This condition needs to be evaluated thoroughly because Teluk Berau #02 is located in an area that produces coal so that transportation costs are cheaper. Of the 10 largest CFPPs that have large operational costs compared to the price of electricity production, all of them are CFPPs located outside Java. Where this condition can also be caused by the centre of the Indonesian economy which is still dominant on Java.

As an effort to actively participate in climate change, CFPPS also needs to pay attention to CO2 emission conditions. On average, every 1 ton of coal produces 52,272,593 CO2 per year, according to Table 6.

Figure 4: Changes in productivity in 2021-2022

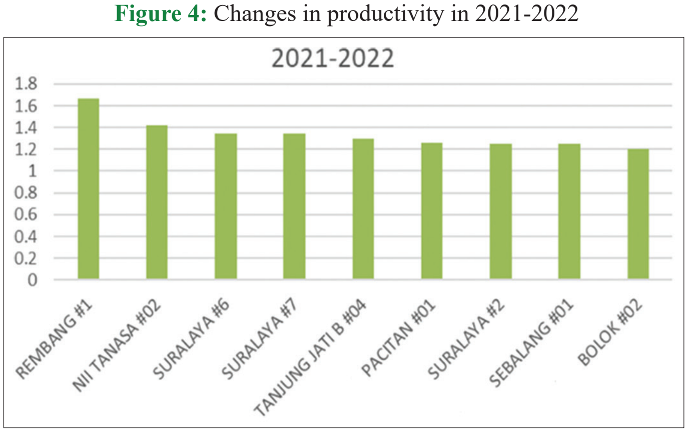


Table 3: 2022 VRS TE values

NO	CFPPs	Efficiency
1	ADIPALA #01	1
2	AMURANG #01	1
3	HOLTEKAMP #01	1
4	HOLTEKAMP #02	1
5	JERANJANG #01	1
6	JERANJANG #02	1
7	JERANJANG #03	1
8	KETAPANG #01	1
9	KETAPANG #02	1
10	LABUHAN ANGIN #02	1
11	NII TANASA #01	1
12	NII TANASA #02	1
13	PACITAN #02	1
14	SEBALANG #01	1
15	SINTANG #01	1
16	SINTANG #02	1
17	SINTANG #03	1
18	SUMBAWA BARAT UNIT #2	1
19	SURALAYA #6	1
20	TANJUNG JATI B #01	1
21	TANJUNG JATI B #02	1
22	TANJUNG JATI B #03	1
23	TANJUNG JATI B #04	1
24	TELUK BERAU #01	1
25	TELUK BERAU #02	1
26	TIDORE #02	1

Table 4: Operation Cost CFPPs

CFPPs	Installed Capacity (MW)	Electricity Generated (GWh)	Operation Cost (millions of USD/years)
Tanjung Jati B #04	710.0	4.843	26
Tanjung Jati B #02	710.0	5.607	26
Tanjung Jati B #01	710.0	4.571	24
Tanjung Jati B #03	710.0	5.524	24
Paiton #09	660.0	4.160	1.606
Adipala #01	660.0	4.092	1.502
Suralaya #8	625.0	3.010	32
Suralaya #5	600.0	4.005	34
Suralaya #7	600.0	4.167	34
Suralaya #6	600.0	3.348	32
Paiton #02	400.0	2.526	549
Paiton #01	400.0	2.168	411
Suralaya #3	400.0	3.018	34
Suralaya #1	400.0	3.061	34
Suralaya #4	400.0	2.762	32
Suralaya #2	400.0	2.839	32

Table 5: Top 10 CFPPs with the largest costs (USD/kwh)

CFPPs	Province	Cost USD/kwh
Teluk Berau #02	East Kalimantan	1.09
Sumbawa Barat Unit #1	West Nusa Tenggara	1.08
Tidore #01	North Maluku	1.02
Tidore #02	North Maluku	0.88
Sumbawa Barat Unit #2	West Nusa Tenggara	0.81
Tembilahan #01	Riau	0.79
Sanggau #01	West Kalimantan	0.79
Sanggau #02	West Kalimantan	0.74
Tanjung Balai Karimun #02	Riau Islands	0.72
Tembilahan #02	Riau	0.70

Table 6: Top 10 CFPPs with the largest Coal/CO_2

CFPPs	Installed Capacity (MW)	Province	Coal/CO_2 (ton/CO_2)
Suralaya #8	625.0	Banten	175,228,034
Tanjung Awar-Awar #02	350.0	East Java	172,684,350
Suralaya #7	600.0	Banten	163,653,258
Suralaya #1	400.0	Banten	149,490,349
Pacitan #02	315.0	East Java	149,100,596
Tanjung Jati B #02	710.0	Central Java	147,468,829
Suralaya #5	600.0	Banten	146,835,119
Tanjung Awar-Awar #01	350.0	East Java	146,193,833
Indramayu #03	330.0	West Java	145,947,937
Pacitan #01	315.0	East Java	144,603,940

Suralaya #8 is the largest CFPPs producing CO2, this problem is also experienced by 10 CFPPs that are included in the top 10. The CFPPs is located on the island of Java so it requires sea transportation to transport coal. This can be possible due to the coal transportation process which reduces quality.

5. CONCLUSION

Indonesia, which is a developing country, is trying to improve its economy, this is reflected in the increase in electricity consumption every year. This condition needs to be addressed because the generators that are increasing are CFPPs that use coal as raw material.

The results of calculating the efficiency of CFPPs in Indonesia in 2022 state that around 23% of CFPPs are in efficient condition. While the rest are in an inefficient condition, these CFPPs can be optimized in the future by benchmarking against their respective peers and improving targets for increasingly efficient CFPPs in Indonesia.

CFPPs located near coal mines have higher operational costs compared to CFPPS located in the centre of the economy. This can happen because the maintenance costs may be higher. However, the CFPPS has a low CO2 emission level. The low CO2 emission level is due to the coal delivery process which is not too far so that the quality is still good. CFPPs located in the centre of the economy has lower operational costs, but the CO2 emission level is less. This condition is a result of the coal transportation process which reduces its quality. In reducing the operational costs of CFPPs without eliminating environmental aspects, a study needs to be conducted in the construction of CFPPs which has low operational costs and also low CO2 emissions.

Future research in similar fields can update existing data with a longer and more recent time span. It is hoped that expanding the time span can measure changes in productivity more accurately and objectively to determine the future. Calculation of efficiency with two stage DEA to obtain a broader and deeper analysis regarding measurements. Adding a stage to the DEA calculation can help the company under study have a more objective measurement value, because this research has limited variables used.

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APPENDIX

NO	CFPPs	Capacity (MW)	Electricity production (GWh)	Operating costs (millions of USD/years)	Cost (USD/kWh)	Coal Ton/ CO_2	Province
1	Adipala #01	660.0	4,092	1,507.8	0.37	252,308.08	Central Java
2	Air Anyir #01	30.0	160	4.0	0.03	13,269.33	Bangka Belitung
3	Air Anyir #02	30.0	137	3.0	0.02	11,550.01	Bangka Belitung
4	Amurang #01	25.0	74	3.6	0.05	19,393.14	North Sulawesi
5	Amurang #02	25.0	87	3.6	0.04	22,782.38	North Sulawesi
6	Anggrek #1	27.5	65	2.3	0.03	6,605.05	Gorontalo
7	Anggrek #2	27.5	79	2.3	0.03	7,608.39	Gorontalo
8	Asam-Asam #01	65.0	385	16.9	0.04	23,710.32	South Kalimantan
9	Asam-Asam #02	65.0	443	22.1	0.05	26,897.42	South Kalimantan
10	Asam-Asam #03	65.0	373	16.1	0.04	23,258.06	South Kalimantan
11	Asam-Asam #04	65.0	458	24.9	0.05	29,245.24	South Kalimantan
12	Barru #01	50.0	301	12.4	0.04	27,906.74	South Sulawesi
13	Barru #02	50.0	258	12.4	0.05	23,737.32	South Sulawesi
14	Bengkayang #01	50.0	236	7.9	0.03	34,349.73	West Kalimantan
15	Bengkayang #02	50.0	256	9.0	0.04	29,753.29	West Kalimantan
16	Bolok #01	16.5	122	2.0	0.02	10,648.86	East Nusa Tenggara
17	Bolok #02	16.5	136	2.5	0.02	12,205.18	East Nusa Tenggara
18	Bukit Asam #01	65.0	301	7.8	0.03	20,238.02	South Sumatra
19	Bukit Asam #02	65.0	408	14.1	0.03	26,973.10	South Sumatra
20	Bukit Asam #03	65.0	384	12.8	0.03	26,691.50	South Sumatra
21	Bukit Asam #04	65.0	389	13.3	0.03	27,337.50	South Sumatra
22	Holtekamp #01	12.0	31	0.2	0.01	3,781.12	Papua
23	Holtekamp #02	12.0	37	0.3	0.01	4,586.39	Papua
24	Indramayu #01	330.0	1,973	331.3	0.17	138,929.46	West Java
25	Indramayu #02	330.0	2,020	349.6	0.17	143,198.02	West Java
26	Indramayu #03	330.0	2,054	361.8	0.18	145,947.94	West Java
27	Jeranjang #01	30.0	183	4.7	0.03	17,675.96	West Nusa Tenggara
28	Jeranjang #02	30.0	179	4.6	0.03	18,725.96	West Nusa Tenggara
29	Jeranjang #03	30.0	168	4.1	0.02	16,624.70	West Nusa Tenggara
30	Ketapang #01	10.0	52	0.6	0.01	22,998.52	West Nusa Tenggara
31	Ketapang #02	10.0	60	0.9	0.01	31,711.67	West Kalimantan
32	Labuan #01	300.0	1,681	240.6	0.14	78,330.87	West Kalimantan
33	Labuan #02	300.0	2,038	373.8	0.18	98,221.47	Banten
34	Labuhan Angin #01	115.0	235	5.9	0.03	26,254.75	Banten
35	Labuhan Angin #02	115.0	274	7.9	0.03	30,004.73	North Sumatra
36	Lontar #01	315.0	1,957	341.0	0.17	81,255.64	North Sumatra
37	Lontar #02	315.0	2,173	429.2	0.20	89,333.64	Banten
38	Lontar #03	315.0	1,793	281.5	0.16	73,644.10	Banten
39	Nagan Raya #01	110.0	605	50.6	0.08	34,135.97	Aceh
40	Nagan Raya #02	110.0	514	35.0	0.07	27,787.62	Aceh
41	Nii Tanasa #01	12.0	65	2.6	0.04	3,997.21	Southeast Sulawesi
42	Nii Tanasa #02	12.0	53	2.6	0.05	3,307.21	Southeast Sulawesi
43	Ombilin #01	100.0	569	16.0	0.03	22,051.58	West Sumatra
44	Ombilin #02	100.0	220	2.6	0.01	11,302.12	West Sumatra
45	Pacitan #01	315.0	1,962	347.1	0.18	144,603.94	East Java
46	Pacitan #02	315.0	2,034	369.3	0.18	149,100.60	East Java
47	Paiton #01	400.0	2,168	413.2	0.19	104,414.06	East Java
48	Paiton #02	400.0	2,526	551.7	0.22	124,105.64	East Java
49	Paiton #09	660.0	4,160	1,612.7	0.39	186,701.69	East Java
50	Palabuhan Ratu #01	350.0	1,825	298.1	0.16	93,807.46	East Java
51	Palabuhan Ratu #02	350.0	2,169	420.1	0.19	109,633.66	East Java West
52	Palabuhan Ratu #03	350.0	1,990	352.3	0.18	100,591.59	West Java
53	Pangkalan Susu #01	220.0	1,020	115.2	0.11	77,242.31	West Java
54	Pangkalan Susu #02	220.0	1,048	115.7	0.11	63,077.95	North Sumatra

NO	CFPPs	Capacity (MW)	Electricity production (GWh)	Operating costs (millions of USD/years)	Cost (USD/kWh)	Coal Ton/ CO_2	Province
55	Pangkalan Susu #03	200.0	984	104.1	0.11	55,954.86	North Sumatra
56	Pangkalan Susu #04	200.0	1,121	139.3	0.12	74,074.98	North Sumatra
57	Pulang Pisau #01	60.0	286	10.3	0.04	19,163.60	North Sumatra
58	Pulang Pisau #02	60.0	323	12.8	0.04	21,060.46	Central Kalimantan
59	Punagaya #01 (Harbin)	110.0	691	33.7	0.05	55,608.22	Central Kalimantan
60	Punagaya #02 (Harbin)	110.0	651	31.7	0.05	52,396.36	South Sulawesi
61	Rembang #1	315.0	1,542	33.7	0.02	83,863.90	South Sulawesi
62	Rembang #2	315.0	1,652	31.7	0.02	111,986.49	Central Java
63	Ropa #01	7.0	48	33.7	0.70	4,078.50	Central Java
64	Ropa #02	7.0	50	31.7	0.64	4,337.23	East Nusa Tenggara
65	Sanggau #01	7.0	42	33.7	0.80	4,478.84	East Nusa Tenggara
66	Sanggau #02	7.0	43	31.7	0.75	4,407.74	West Kalimantan
67	Sebalang #01	100.0	568	33.7	0.06	64,012.55	West Kalimantan
68	Sebalang #02	100.0	585	31.7	0.05	58,362.98	lampung
69	Sintang #01	7.0	49	30.2	0.62	5,123.25	lampung
70	Sintang #02	7.0	45	29.1	0.64	6,957.13	West Kalimantan
71	Sintang #03	7.0	40	24.4	0.61	7,218.41	West Kalimantan
72	Suge #01	16.5	87	28.3	0.33	13,835.04	West Kalimantan
73	Suge #02	16.5	104	24.4	0.23	18,001.77	Bangka Belitung
74	Sumbawa Barat Unit #1	8.5	24	26.1	1.08	3,785.71	Bangka Belitung
75	Sumbawa Barat Unit #2	8.5	39	31.7	0.82	4,382.84	West Nusa Tenggara
76	Suralaya #1	400.0	3,061	33.7	0.01	149,490.35	West Nusa Tenggara
77	Suralaya #2	400.0	2,839	31.7	0.01	130,784.81	Banten
78	Suralaya #3	400.0	3,018	33.7	0.01	137,531.68	Banten
79	Suralaya #4	400.0	2,762	31.7	0.01	138,261.39	Banten
80	Suralaya #5	600.0	4,005	33.7	0.01	146,835.12	Banten
81	Suralaya #6	600.0	3,348	31.7	0.01	135,386.32	Banten
82	Suralaya #7	600.0	4,167	33.7	0.01	163,653.26	Banten
83	Suralaya #8	625.0	3,010	31.7	0.01	175,228.03	Banten
84	Tanjung Awar-Awar #01	350.0	1,964	33.7	0.02	146,193.83	Banten
85	Tanjung Awar-Awar #02	350.0	2,313	31.7	0.01	172,684.35	East Java
86	Tanjung Balai Karimun #01	7.0	51	32.0	0.63	7,675.15	East Java
87	Tanjung Balai Karimun #02	7.0	36	26.1	0.73	4,989.56	Riau Islands
88	Tanjung Jati B #01	710.0	4,571	24.1	0.01	136,034.69	Riau Islands
89	Tanjung Jati B #02	710.0	5,607	26.1	0.00	147,468.83	Central Java
90	Tanjung Jati B #03	710.0	5,524	24.1	0.00	126,080.86	Central Java
91	Tanjung Jati B #04	710.0	4,843	26.1	0.01	115,708.21	Central Java
92	Tarahan #03	100.0	696	24.1	0.03	35,697.61	Central Java
93	Tarahan #04	100.0	694	26.1	0.04	28,297.84	lampung
94	Teluk Balikpapan #01	110.0	658	24.1	0.04	40,072.94	lampung
95	Teluk Balikpapan #02	110.0	574	26.1	0.05	35,504.68	East Kalimantan
96	Teluk Berau #01	9.5	48	29.1	0.60	15,172.06	East Kalimantan
97	Teluk Berau #02	9.5	29	31.7	1.09	10,885.48	East Kalimantan
98	Teluk Sirih #01	112.0	471	33.7	0.07	36,706.22	East Kalimantan
99	Teluk Sirih #02	112.0	506	31.7	0.06	41,777.86	West Sumatra
100	Tembilahan #01	7.0	38	30.2	0.80	4,702.65	Sumatera West
101	Tembilahan #02	7.0	44	30.7	0.70	5,422.37	Riau
102	Tenayan #01	110.0	545	33.7	0.06	54,187.38	Riau
103	Tenayan #02	110.0	604	31.7	0.05	51,588.71	Riau
104	Tidore #01	7.0	33	33.7	1.02	7,540.55	Riau
105	Tidore #02	7.0	36	31.7	0.88	41,511.59	North Maluku