Improve the efficiency of the energy services at national electricity company (PLN) using data envelopment analysis (DEA)

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Abstract. The indicators of economic improvement in energy efficiency have been measured and evaluated globally, one of them was the consumption of energy. However, in Indonesia, the increase in energy efficiency has not been optimally improved in terms of energy consumption, especially for fossil fuel energy consumption and GHG emission. This was caused by the energy resources which was heavily relied on coal-fired power generation and imported crude oil. This paper proposed a solution by providing a good energy efficiency measurement based on the well-developed DEA technique. This study was aimed to provide acceptable energy efficiency, especially any single rupiah of the GRDP produced the people had to consume energy in Indonesia. Thus, optimizing energy efficiency was a key to reduce import dependency, support the green economy, and bring down costs for consumers. This research used input-oriented DEA based on the Charnes, Cooper, and Rhodes (CCR) model to assess the efficiency scores of PLN in Indonesia implemented in the period 2017. The result revealed that the consumption of energy that any single rupiah of GRDP produced, the provinces at Jawa, Bali, Sumatra, Papua, Maluku, and Nusa Tenggara had to consume energy more than one at Kalimantan and Sulawesi. Based on this study, fossil fuel energy consumption and GHG emissions performance in PLN were very crucial for the future of energy assessment in Indonesia.

Keywords: Data Envelopment Analysis (DEA), Energy efficiency, PLN

1. Introduction
The Sustainable Development Goals (SDGs) are the pathway to achieve a better sustainable future in which all countries are racing ahead toward the goal and target by 2030. One of the global challenges the world is facing now is climate change because 60% of total greenhouse gas (GHG) emissions are the form of energy uses. One of the ways of reducing GHG emissions is to double the improvement rate of global energy efficiency. This has prompted the nations to discuss or debate their energy security challenges and prospects [1]. In this context, the rapid progress of economic and social development has increased pressure on the environment because the power sector in Indonesia has relied heavily on the coal-fire generation and imported crude oil [2].

Globally the SDGs have not only 17 goals that break into 169 specific targets, but also 232 indicators that need to be measured and assessed. To ensure SDGs7, Indonesia should improve the ratio of national

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energy efficiency. For instance, in terms of energy use in electricity production Indonesia had to consume more energy than G-20 countries in 2000 [4]. Because of the importance of measurement of the assessment of SDGs, the sustainability analysis has been attracted to many scholars in the last several years. Sustainability analysis was represented from seven different perspectives but related to each other as seen in figure 1. The well-developed technique was the DEA approach which has been used widely by policymakers to assess the sustainability performance of SDG7 all over the world. This instrument was designed to measure energy efficiency with very wide application in various fields.

![Figure 1. Perspective and Tools of Sustainability Analysis](image)

According to National Electricity Planning, to achieve the SDGs in Indonesia, State Electricity Company (PLN) in Indonesia was expected to generate new electricity capacity at a rate of 9.2% annually up until 2027. To achieve this target, the government has implemented two fast track 10,000MW programs, which have been relied most on coal-fired power generation. As a net importer of crude oil, the government restrict the import of crude oil using the Energy Law 2007 which required the energy mix of 2025 to be: coal (30%), oil (20%), gas (30%), hydro and renewable (5%), geothermal (5%), biofuel (5%) [5]. This research was undertaken to evaluate the efficiency of energy services at PLN in Indonesia.

2. Research Method
The method used in this study was quantitative including descriptive analysis followed by an exploration of data such as graphs and tables. The assessment of energy efficiency was done using indicators from model 1 of DEA sustainability. DEA was a methodology using the application of linear programming based on the efficiency measurement of inputs variables and output variables with Frontier Analyst Banxia software. The steps for assessing the relative performance of a set of locations, called Decision-Making Units was followed by the assessment using steps by the author [6]. The indicators used here were the inputs variables such as CO₂ emissions and Fossil fuel energy consumption (FOSS) (table 1). The data of CO₂ emission was calculated from the GHG equivalencies calculator, while FOSS and FNOSS data were explored from the KESDM database [7]. The Gross Regional Domestic Product (GRDP) data was explored from the Central Bureau of Statistics Indonesia [8]. This research was carried out in 2019.
Table 1. Data on carbon emissions, energy consumption, and GDP for selected provinces in Indonesia, 2017

| Province                        | Emission CO₂ (million metric ton) | FOSS (TWh) | GRDP (trillion) | FNOSS (GWh) |
|---------------------------------|-----------------------------------|------------|-----------------|-------------|
| Jawa Bali                       | 232                               | 259        | 6,002.23        | 20          |
| Sumatra                         | 49                                | 21         | 2,133.22        | 4           |
| Kalimantan                      | 13                                | 7          | 843.12          | 0.15        |
| Sulawesi                        | 13                                | 3          | 603.45          | 1.8         |
| Papua, Maluku, Nusa Tenggara   | 7                                 | 4          | 414.19          | 0.15        |

Source: [7,8]

The basic models of the DEA were originated from the input-oriented Charnes, Cooper, and Rhodes (CCR) model which included the constant returns to scale (CRS), more detailed can be obtained from previous authors. Suppose we have a set of n DMUs. Each DMU \( j = 1, \ldots, n \), produces \( s \) different outputs \( y_{rj} \) \( (r = 1, \ldots, s) \) using \( m \) different inputs \( x_{ij} \) \( (i = 1, \ldots, m) \).

In mathematical programming:

\[
\max h_0 (u, v) = \frac{\sum r u_r y_{ro}}{\sum i v_i x_{io}}
\]  \hspace{1cm} (1)

The optimal value of the objective function of model 1 of DEA sustainability was that the score of CRS efficiency was equal to 1 (or 100%) which was acted as an interstate benchmarking.

3. Results and Discussion

The CRS model used here was based on model 1 which consisting of 1 undesirable input, 1 desirable input and 2 desirable output as reported by the previous author [9]. However, the CRS model can be developed to model 2 which consisting of the efficiency measure and its reference technology [10]. Using input orientation for DEA analysis, the input and output data as seen in table 2, were analyzed by the DEA frontier analysis application program. The program produced efficiency related to rating sustainability for every province in Indonesia. The efficiency score was classified into two optimization modes presented in table 3. The first optimization modes aimed to minimize the input to produce the same outputs. It turned out that the consumption of energy that any of rupiah of GRDP produced the people at Jawa Bali had to consume more than one of other provinces.

Table 2. Relative efficiencies and peers, 2017

| Unit name                          | CRS Efficiency | Peers                        | Condition |
|------------------------------------|----------------|------------------------------|-----------|
| Jawa Bali                          | 62.3%          | Sulawesi                     | ∙         |
| Kalimantan                         | 100%           | -                            | ∙         |
| Papua, Maluku, and Nusa Tenggara  | 93.6%          | Kalimantan & Sulawesi        | ☢         |
| Sulawesi                           | 100%           | -                            | ☢         |
| Sumatra                            | 83.3%          | Kalimantan & Sulawesi        | !         |

Similarly, the latter sought to maximize outputs with the inputs given. Both optimization modes produced the same results where Jawa and Bali have the worst energy efficiency. On the contrary, Kalimantan and Sulawesi were the regions that have become the peer because the standard reference for CRS efficiency scores was 100%.

Peer illustrated the benchmark for a location to be efficient. Figure 2 provided the target projection on carbon emissions, energy consumption, and GRDP for the selected islands in Indonesia. In this case, the reference for Jawa and Bali to be sustainable was Sulawesi, respectively. To achieve sustainable
energy efficiency, the target input of emission CO$_2$ and FOSS should be reduced to 37.74% and 87.13, respectively. So, to get an optimum target to achieve sustainability, the output target of GRDP increased to 11.71%. Other provinces’ interpretation was using the same analogy. In general, by using sustainability analysis (DEA technique) it turned out Sulawesi and Kalimantan have the highest sustainability value. Jawa was the lowest value of sustainability because of high fossil energy consumption and CO$_2$ emission from power plants. To give a more profound analysis of energy performance and emission performance, the correlation between time-varying and cross-sectional data can be compared using the DEA windows analysis technique as reported from the previous author [11].

![Image](https://example.com/image.png)

**Figure 2.** Potential improvement scores of efficiency in (a) Jawa Bali, (b) Papua Maluku Nusa Tenggara, (c) Sumatra; with reference unit in (A) Sulawesi, (B) Kalimantan, respectively

The comparison of CCR scores showed that energy wasted when energy efficiency was not implemented at Jawa Bali. Hence, wasting energy was unnecessary. The using of technology such as smart-grid infrastructure would require less energy to perform the same function at Jawa Bali. It would have energy-saving opportunities in reducing energy use by 87% and an increase of 11% of GRDP produced. This was similar to another report [12]. Moreover, energy efficiency together with renewable energy resulted in higher shares of renewable energy and a faster reduction in emission of CO$_2$ emissions [13].

4. **Conclusion**

The assessment of energy efficiency at PLN in entire provinces in Indonesia were measured in term of energy and CO$_2$ emission performance by using electricity production and GRDP produced in 2017. For this purpose, two optimization modes (minimizing input and maximizing output) CRS models 1 of DEA were used. The results in both modes showed the same indicator of efficiency score of which the reference standard for the CRS score in both modes was Sulawesi and Kalimantan. The discrepancy of efficiency score between Jawa Bali and reference standard of the CRS score in Sulawesi and Kalimantan indicated it was urgent to improve the efficiency of energy services in Jawa Bali. In Jawa Bali, the 87% reduction of energy consumption that the 11% increase of rupiah of GRDP produced, the Jawa Bali would have to consume energy as same as the peers. In Sumatra, the 36% reduction of energy consumption that any rupiah of GRDP produced, the Sumatra would have to consume energy as same as the peers. Papua, Maluku, Nusa Tenggara were less efficient than their peers. In this sense, Kalimantan and Sulawesi were efficient because the consumption of energy of any rupiah GRDP
produced, they had to consume energy less than other provinces. We believe it was very critical to improve the energy efficiency of energy services at PLN because energy wasted when the discrepancy of the CRS score among the provinces was big. Renewable energy could not be built up if efficiency energy was not implemented. Furthermore, the emission of CO$_2$ would reduce rapidly when energy efficiency and renewable energy were implemented together.

5. References

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