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# THE ROLE OF RENEWABLE ENERGY IN EFFICIENCY OF GRDP GROWTH: A DEA APPROACH

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**Abstract**
*Indonesia's economy is currently still plagued by the Middle Income Trap—a country's inability to sustain stable annual economic growth, as reflected in its GDP figures. Indonesia's economic productivity also faces challenges related to the uneven distribution of economic development across provinces, as evidenced by disparities in regional GDP (PDRB). Given the global trend toward green innovations, such as renewable energy, this study aims to determine whether the level of utilization of renewable energy power plants in a province can enhance efficiency in regional GDP growth. The methods used to compare the efficiency levels of 38 provinces in Indonesia are DEA with an output-oriented approach and VRS, using inputs consisting of installed capacity of renewable energy power plants and installed capacity of non-renewable energy power plants, as well as output in the form of GRDP values. The results indicate that the slack in the installed capacity of non-renewable power plants tends to be higher (697,819 MW) than that of renewable power plants (359,729 MW). There are 5 provinces classified as efficient, but 3 provinces are considered outliers; thus, the truly efficient provinces are Yogyakarta Special Region and West Sulawesi, with a DEA efficiency score of 1. Efficient provinces tend to have a larger installed capacity of renewable power plants compared to non-renewable ones. Therefore, it is recommended that stakeholders intensify the use of renewable energy as the primary source of electricity generation to achieve more efficient economic growth and address regional GDP disparities.*



## INTRODUCTION

Indonesia is the world's largest archipelago, comprising 16,722 islands and covering a land area of 1,892,255.47 km², according to data from the Minister of Home

Affairs' Decree No. 050-145 of 2022 on the Assignment and Update of Codes, Administrative Territorial Data, and Islands for the Year 2021. With such a vast territory, Indonesia's population continues to grow each year, as indicated by data from the Central Statistics Agency (BPS): in 1960, the population of Indonesia was 93,928,500 and increased by 188% by 2020 to 270,203,900, with a population density of 145 people per 1 km² when calculated mathematically (Dimyati, 2024). Given its vast territory and large population, Indonesia must prioritize the quality of life for its people, which can be achieved by fostering an inclusive and sustainable economy to enhance the nation's productivity (B. R. Ramadhan & Haura, 2025). Unfortunately, Indonesia's economy is currently still plagued by the Middle Income Trap—a nation's inability to sustain annual economic growth at a stable rate of at least 6% per year, with an annual increase of 1.3%; while Indonesia's economic growth as of 2022 remains at 5.4%, meaning it would take approximately another 30 years to escape this issue (Maryanti et al., 2023). A country must be capable of implementing effective economic transformation to address the complex structural changes in the global economy, ensuring its economic growth remains dynamic and sustainable in the long term (Harahap & Fajariadha, 2026).

One of the structural shifts impacting the global economy is the transition toward renewable energy or green energy. There is a global trend toward green innovations, such as renewable energy, as they can reduce the amount of energy consumption required and have a positive impact on economic sustainability (Jiang in Maryanti et al., 2023). This economic transformation is undertaken with the aim of increasing a country's productivity from a low level to a high level, which is reflected in the country's GDP. Indonesia's GDP per capita as of 2025, according to BPS data, is USD5,083, ranking fifth among other Southeast Asian countries, such as Singapore, which reached USD87,884 in first place. In addition to the low GDP per capita—which only ranks fifth in Southeast Asia—Indonesia's economic productivity also faces issues related to the uneven distribution of the economy across provinces. This is demonstrated by BPS data showing that the Gross Regional Domestic Product (GRDP) per capita of provinces in Indonesia in 2024 tends to vary significantly, such as the province with the highest GRDP per capita on the island of Kalimantan, namely East Kalimantan, which reached Rp212,117 thousand, while the highest on the island of Sulawesi, namely Central Sulawesi, only reached Rp120,750 thousand (Central Statistics Agency, 2026). The RDP per province is shown in Table 1, which is cited from BPS data.

In this article, the author will analyze the GRDP of 38 provinces in Indonesia in the context of their installed power generation capacity, which is grouped into two categories: renewable and non-renewable power plants.

## LITERATURE REVIEW

Two previous studies were also considered in this research. The study by Ul et al. (2024), titled "Role of renewable, non-renewable energy consumption and carbon emission in energy efficiency and productivity change: Evidence from G20 economies," aims to evaluate energy efficiency and changes in productivity among G20 member countries from 1995 to 2020 using the Slack-Based DEA method, accompanied by the Malmquist-Luenberger (ML) index. There are four input-output combination scenarios in this study, namely: 1) inputs consisting of labor, Gross Fixed Capital Formation (an indicator of physical investment), non-renewable energy consumption, and outputs consisting of GDP and carbon emissions; 2) labor, Gross Fixed Capital Formation (an indicator of physical investment), non-renewable energy consumption, plus a new input of renewable energy consumption, and outputs of GDP and carbon emissions; 3) labor, Gross Fixed Capital Formation (an indicator of physical investment), and renewable energy consumption only—since non-renewable energy consumption was excluded—with GDP as the sole output, as carbon emissions were excluded; 4) labor, Gross Fixed Capital Formation (an indicator of physical investment), and renewable energy consumption, with both GDP and carbon emissions reintroduced as outputs. The average efficiency scores for these four scenarios, in order, are: 0.7837; 0.8578; 0.6399; 0.66778. The implications of these results are that when only labor, physical investment, and non-renewable energy consumption serve as inputs, with GDP and carbon emissions as outputs (Scenario 1), the efficiency level is quite low (0.7837). This means there is still room for improvement of 0.2617 points by reducing input quantities—such as non-renewable energy consumption—or by increasing GDP and reducing carbon emissions. However, when renewable energy consumption is added as an input (Scenario 2), the efficiency level increases to 0.8578, thereby reducing the room for improvement. This is due to technological advancements that drive GDP growth, as renewable energy is synonymous with technological innovation, which simultaneously drives a reduction in carbon emissions. Regarding the ML index, the value in Scenario 1 is higher (1.0064) than in Scenario 2 (0.9988), indicating an increase in energy productivity due to the addition of renewable energy consumption inputs. The next comparison is when non-renewable energy consumption inputs are no longer included and carbon emissions outputs are excluded (Scenario 3) to examine the ML index value, which measures energy efficiency; the average efficiency score is 0.6399 and the average ML index is 0.9934. This indicates that although non-renewable energy consumption generates significant carbon emissions, its role remains crucial in GDP growth; furthermore, an ML index below 1 suggests that G20 countries have not yet maximized the use of renewable energy consumption to boost GDP. In the fourth scenario, when carbon emissions are reintroduced to examine their impact on the productivity of renewable energy consumption, the efficiency score stands at 0.66778, indicating a potential improvement of 0.3222 points—achievable either by reducing input levels or by increasing GDP while reducing carbon emissions—and the ML index is 1.0044. This indicates that energy efficiency and productivity scores will increase if the carbon emissions variable is added as an output, highlighting the vital role of renewable energy consumption in reducing carbon emissions.

The second study is by Veronese et al. (2023), titled "A data envelopment analysis approach to measuring socio-economic efficiency due to renewable energy sources in Brazilian regions," which aims to calculate the relative efficiency scores of mesoregions in Brazil that have power plants, linked to environmental and socio-economic dimensions, using the DEA technique. The output variables used were the number of workers, GDP, and the amount of carbon emissions successfully reduced. The input variables used were the Levelized Cost of Energy (LCOE)—the sum of capital and operating costs required to run a power plant—and the Social-Economic Vulnerability Index (SEVI), a measure of socio-economic vulnerability included to assess how LCOE impacts a region's GDP given existing socio-economic vulnerabilities. The research results show that mesoregions relying on renewable power plants, such as nuclear, wind, and photovoltaic (solar), have better efficiency scores than mesoregions relying on non-renewable power plants, such as gas, coal, and biomass. Additionally, mesoregions that rely on renewable power generation can also generate better GDP growth and create more jobs. For example, mesoregions that rely on wind power generate an average efficiency score of 0.9969, photovoltaics 0.8051, and those relying on both 0.8792, while those relying on biomass have an average efficiency score of only 0.6543 and gas 0.2312.

The similarity with the first study is that both employ the DEA technique, incorporating input variables such as renewable and non-renewable energy, as well as an output variable such as GDP. The difference lies in the types of input and output variables: in that study, the input variables for renewable and non-renewable energy used were energy consumption levels, whereas in this study, the installed capacity of power plants was used, although both indicate the level of energy relied upon. Additionally, other input variables used in that study—namely the number of workers and physical investment—are not used in this study because the installed capacity of power plants is considered to already reflect energy consumption, the number of workers in the energy sector, and physical investment in the energy sector simultaneously; since the construction of installed power plant capacity naturally requires labor and investment during the construction process. In terms of output variables, this study does not include carbon emissions because it focuses on regional economic growth in the form of GRDP, as the units being compared are at the regional level and do not focus on environmental aspects, whereas that study focuses on cross-country economic growth and thus uses GDP alongside carbon emission reductions. Additionally, since this study's data is cross-sectional rather than panel data, it cannot employ the ML index, distinguishing it from that study.

A commonality with the second study is the use of input variables representing energy levels within a region and output variables in the form of GDP, utilizing DEA methodology. The difference lies in the energy level input variable used, which employs the unit of costs incurred and does not directly distinguish between renewable and non-renewable energy; instead, it aggregates all energy costs incurred within a region and then categorizes the region based on the magnitude of the energy level used—whether it relies more on renewable or non-renewable energy. Furthermore, this study does not include SEVI (socio-economic vulnerability) as an input variable because it focuses solely on economic aspects. Regarding output variables, unlike the first study—which included carbon emissions as a variable—this study does not include them because it does not focus on environmental aspects.

## RESEARCH METHODOLOGY

The author estimates the input efficiency frontier by assuming an output-oriented function using Benchmarking, which measures how quickly or efficiently various approaches or units complete the same task. This is based on the premise that DMUs (decision-maker units) must maximize output within the model to improve their efficiency scores. The Benchmarking model is a technique that compares different units to explain relative efficiency calculations among them (Veronese et al., 2023). This technique or method focuses on estimating the efficient production frontier in a specific market—that is, a set of inputs and outputs that produces the maximum possible quantity given the inputs. Estimating the efficient production frontier can be done using parametric or non-parametric techniques; the method used in this study is DEA, which employs linear programming to estimate the efficiency scores of the compared DMUs and falls under non-parametric techniques (Veronese et al., 2023). The advantage of DEA over parametric techniques is that its model does not require assumptions about specific function forms to assess efficiency levels. This technique is suitable for research aimed at identifying inefficient inputs and the best ways to improve model efficiency by optimizing those inefficient inputs (Fidanoski & Simeonovski, 2021).

The DMUs under comparison are 38 provinces in Indonesia based on their existing installed power plant capacity. The authors selected two input variables from the installed capacity data of each province by power plant type, grouped into renewable and non-renewable sources, using the same data source: the 2024 data from the Directorate General of Electricity, measured in MW. This analysis considers renewable power plants, namely hydroelectric power plants (PLTA), wind power plants (PLTB), biomass power plants (PLT Bio), geothermal power plants (PLTP), solar power plants (PLTS), and gas-fired power plants (PLTGB). Non-renewable power plants, namely coal-fired power plants (PLTU), gas-fired power plants (PLTG), and diesel-powered power plants (PLTD), are also considered. Other types of power plants are not considered in this study due to their negligible values in the electricity matrix. The installed capacity values of the four types of non-renewable power plants will be summed for each province, as will those of the three types of renewable power plants. Next, the DEA output variable was selected to represent the dimension of efficiency to be analyzed, namely the economic dimension in the form of the GRDP of each province in Indonesia. The author used data from BPS for provincial GRDP values in 2024. This DEA model implies that the output variable is the desired outcome and that its increase will make the DMU more efficient.

There are four orientations in DEA: 1) all orientations, which examine efficiency in terms of inputs, outputs, and even non-orientation simultaneously within the DEA model and are appropriate for research requiring a comprehensive perspective; 2) input-oriented, which examines the use of the smallest possible amount of inputs by DMUs while maintaining a constant output level and is suitable for institutions seeking to reduce resource usage; 3) output-oriented, which examines the production of the largest possible output while maintaining a constant input level and is suitable for institutions seeking to increase output using the same resources; 4) non-oriented, also known as the additive approach, which examines the efficiency of both inputs and outputs simultaneously and is suitable for institutions seeking comprehensive efficiency improvements (Sihombing et al., 2024).

DEA also has two types of analysis. The first is constant returns to scale (CRS), developed by Charnes, Cooper, and Rhodes in 1978, where all units within a production set are compared, and efficiency levels are calculated under the assumption that all outputs are driven by the same factors, as their quantities are considered to represent the radial distances from the existing efficiency frontier. The second is variable returns to scale (VRS), developed by Banker in 1984 to address the limitations of the CRS model. It shares the same assumption that input contraction is radial, but the movement of output from the compared units in the DEA model is constrained by the addition of specific boundaries (Veronese et al., 2023). In other words, the CRS model assumes that input contraction will change output in the same proportion or by the same distance and is suitable for institutions where all units operate at the same level of optimization, whereas the VRS model assumes that the units compared in DEA can move at rates different from the rate of contraction in inputs, making it suitable for institutions with units that have diverse conditions and operations (Sihombing et al., 2024).

In this study, the author employs an output-oriented DEA model, meaning that decision-makers need to observe output variables as controllable variables in an effort to improve efficiency levels (Veronese et al., 2023). This means that output variables can be maximized or minimized according to the decision-maker's will because they are manageable and are accompanied by calculations of efficient input levels. This is because the GRDP value is expected to reach the maximum possible figure with minimal input, namely the installed capacity of power plants, both renewable and non-renewable. The assumption used in this study is the VRS, which posits that only input variables can affect output variables, not the other way around; because if the input is increased by one unit, the output may increase by more or less than one unit (Niswati in Ghoni & Arianty, 2021). This is because, in this study, the input variables—namely the installed capacity of renewable and non-renewable power plants—are considered to influence the GRDP value, not the other way around. In this study, the author used Win4DEAP software to run the model analysis because this type of software is considered capable of handling data from various units of measurement (Yandri & Masduki, 2025). The formula for determining the efficiency score is as follows, with the efficiency score ranging from 0–100 percent or 0 to 1 (Adhilla et al., 2025).

$$\text{Efficiency} = \frac{Output}{Input} = \frac{Virtual\ Output}{Virtual\ Input} = \frac{\sum_{r=1}^{s} Ur\ Yr}{\sum_{i=1}^{m} Vi\ Xi}$$

The formula can be expressed as:

$$\frac{U1Y1+U2Y2+\cdots\ldots\ldots+UsYs}{V1X1+V2X2+\cdots\ldots\ldots+VmXm}$$

Where: Yr = the value of output r
Ur = the weighted sum of output r
Xi = the value of input i
Vi = the weighted sum of input i

**Input and Output Variables**

For non-renewable power plants, the distribution across various regions is as follows: 1) Coal-fired power plants (PLTU), as the primary type of power plant accounting for 53.99% of Indonesia's total installed capacity, are generally distributed across all provinces in Indonesia, except for DKI Jakarta, Yogyakarta Special Region, South Sulawesi, Maluku, Papua Pegunungan, South Papua, and Southwest Papua, with the installed capacity of provinces having coal-fired power plants ranging from 24 MW (Papua) to 10,222 MW (Central Java); 2) Gas-fired power plants (PLTG), as the second-largest contributor to national installed capacity at 26%, are distributed across all provinces except Bengkulu, Yogyakarta Special Region, North Sulawesi, West Sulawesi, and Papua Pegunungan, with a range from 22 MW (South Kalimantan) to 5,856 MW (West Java); 3) Diesel power plants (PLTD), which account for 5.78% of the national installed capacity, are distributed across all provinces with a range from 7 MW (Special Region of Yogyakarta) to 382 MW (Jakarta Capital Region) (Secretariat of the Directorate General of Electricity, 2025). From this data, it is evident that the Special Region of Yogyakarta is the province with the least utilization of non-renewable power plants, as it has only one type of non-renewable power plant—the PLTD—and even that has the smallest capacity nationwide. The total installed capacity across all provinces, categorized by renewable and non-renewable power plant types, is shown in Table 1, which is sourced from data provided by the Secretariat of the Directorate General of Electricity.

**Table 1.** Data on Installed Power Plant Capacity and GRDP by Province in 2024

| **Province** | **Installed capacity of non-renewable power plant (MW)** | | | | **Installed capacity of renewable power plant (MW)** | | | | | | | **PDRB (miliar rupiah)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PLTU | PLTG | PLTD | **Total** | PLTA | PLTB | PLT Bio | PLTP | PLTS | PLTGB | **Total** | |
| **Aceh** | 692 | 448 | 230 | **1.370** | 38 | 0 | 17 | 0 | 1 | 0 | **56** | 243202 |
| **Sumut** | 1330 | 1147 | 176 | **2.653** | 1399 | 0 | 331 | 711 | 6 | 0 | **2.447** | 1146919 |
| **Sumbar** | 433 | 43 | 22 | **498** | 324 | 0 | 71 | 89 | 2 | 0 | **486** | 332936 |
| **Riau** | 1292 | 1035 | 173 | **2.500** | 114 | 0 | 786 | 0 | 31 | 0 | **931** | 1112481 |
| **Kepri** | 324 | 665 | 329 | **1.318** | 0 | 0 | 1 | 0 | 16 | 0 | **17** | 352436 |
| **Bengkulu** | 200 | 0 | 49 | **249** | 308 | 0 | 10 | 0 | 0 | 0 | **318** | 103991 |
| **Jambi** | 318 | 282 | 44 | **644** | 1 | 0 | 74 | 0 | 1 | 0 | **76** | 322975 |
| **Sumsel** | 2293 | 823 | 48 | **3.164** | 21 | 0 | 813 | 158 | 6 | 0 | **998** | 663961 |
| **Babel** | 120 | 100 | 145 | **365** | 0 | 0 | 122 | 0 | 3 | 0 | **125** | 107504 |
| **Lampung** | 467 | 173 | 98 | **738** | 206 | 0 | 61 | 229 | 5 | 0 | **501** | 483882 |
| **Banten** | 9012 | 880 | 130 | **10.022** | 16 | 0 | 0 | 0 | 39 | 200 | **255** | 873626 |
| **DKI Jakarta** | 0 | 5014 | 382 | **5.396** | 0 | 0 | 0 | 0 | 41 | 0 | **41** | 3679358 |
| **Jabar** | 4186 | 5856 | 226 | **10.268** | 2285 | 0 | 14 | 1231 | 350 | 0 | **3.880** | 2823338 |
| **Jateng** | 10222 | 2135 | 70 | **12.427** | 372 | 0 | 34 | 73 | 48 | 0 | **527** | 1817776 |
| **DIY** | 0 | 0 | 7 | **7** | 1 | 0 | 4 | 0 | 3 | 0 | **8** | 193514 |
| **Jatim** | 6304 | 3661 | 163 | **10.128** | 307 | 0 | 163 | 0 | 70 | 0 | **540** | 3168295 |
| **Bali** | 380 | 558 | 305 | **1.243** | 3 | 1 | 0 | 0 | 14 | 0 | **18** | 298441 |
| **Kalbar** | 392 | 134 | 301 | **827** | 6 | 0 | 82 | 0 | 6 | 0 | **94** | 300166 |
| **Kalteng** | 389 | 311 | 169 | **869** | 1 | 0 | 407 | 0 | 1 | 0 | **409** | 222864 |
| **Kalsel** | 823 | 22 | 126 | **971** | 30 | 0 | 18 | 0 | 16 | 0 | **64** | 286818 |
| **Kaltim** | 968 | 472 | 268 | **1.708** | 0 | 0 | 60 | 0 | 84 | 0 | **144** | 858430 |
| **Kaltara** | 22 | 97 | 166 | **285** | 2 | 0 | 0 | 0 | 3 | 30 | **35** | 146793 |
| **Sulut** | 373 | 0 | 140 | **513** | 63 | 0 | 0 | 124 | 23 | 0 | **210** | 187374 |
| **Gorontalo** | 176 | 100 | 25 | **301** | 7 | 0 | 1 | 0 | 13 | 0 | **21** | 54554 |
| **Sulteng** | 5845 | 113 | 258 | **6.216** | 645 | 0 | 3 | 0 | 1 | 220 | **869** | 376950 |
| **Sulbar** | 0 | 0 | 2 | **2** | 8 | 0 | 4 | 0 | 1 | 0 | **13** | 64214 |
| **Sulsel** | 1040 | 454 | 156 | **1.650** | 830 | 151 | 17 | 0 | 11 | 0 | **1.009** | 696252 |
| **Sultra** | 108 | 98 | 177 | **383** | 6 | 0 | 0 | 0 | 3 | 0 | **9** | 187374 |
| **NTB** | 418 | 741 | 214 | **1.373** | 19 | 0 | 0 | 0 | 50 | 0 | **69** | 182265 |
| **NTT** | 203 | 119 | 262 | **584** | 10 | 0 | 0 | 24 | 23 | 0 | **57** | 137282 |
| **Maluku** | 0 | 157 | 249 | **406** | 0 | 0 | 0 | 0 | 3 | 0 | **3** | 62646 |
| **Malut** | 5504 | 69 | 165 | **5.738** | 0 | 0 | 0 | 0 | 6 | 0 | **6** | 95787 |
| **Papua** | 24 | 260 | 106 | **390** | 23 | 0 | 0 | 0 | 10 | 0 | **33** | 85914 |
| **Pabar** | 68 | 24 | 71 | **163** | 4 | 0 | 1 | 0 | 13 | 0 | **18** | 76177 |
| **Papteng** | 414 | 43 | 260 | **717** | 0 | 0 | 0 | 0 | 1 | 0 | **1** | 174942 |
| **Papeg** | 0 | 0 | 13 | **13** | 5 | 0 | 0 | 0 | 0 | 0 | **5** | 26561 |
| **Papsel** | 0 | 45 | 31 | **76** | 0 | 0 | 4 | 0 | 2 | 0 | **6** | 33382 |
| **Pabarya** | 0 | 86 | 63 | **149** | 4 | 0 | 3 | 0 | 1 | 0 | **8** | 37040 |
| **Sum** | 54.340 | 26.165 | 5.819 | **86.324** | 7.058 | 152 | 3.101 | 2.639 | 907 | 450 | **14.307** | 22.020.549 |
| **Mean** | 1.430 | 688,5526316 | 153,1315789 | **2.271,684** | 185,7368421 | 4 | 81,60526316 | 69,44736842 | 23,86842105 | 11,84210526 | **376,5** | 579.432,1 |

Source: BPS and the Secretariat of the Directorate General of Electricity and Compiled by the Author (2026)

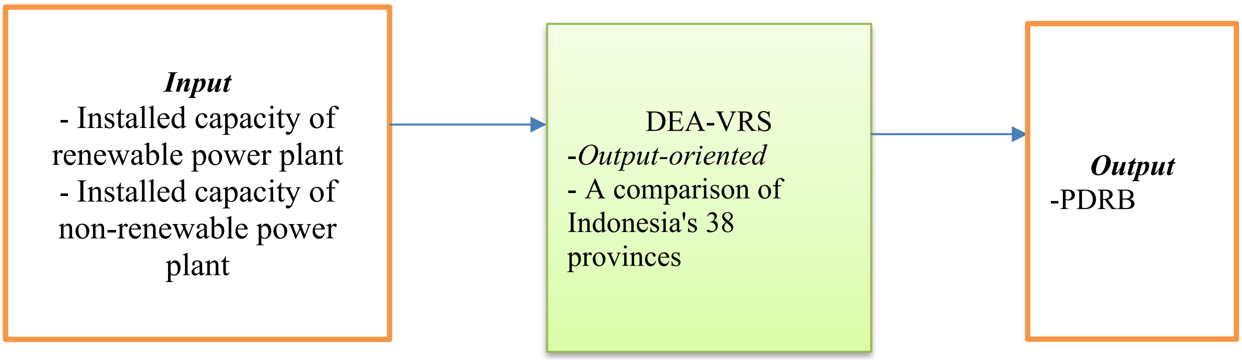


**Figure 1.** Research Framework

**Table 2.** Data Used in the DEA Analysis

| Data | Description | Measurement | Source |
|---|---|---|---|
| ***Input*** | | | |
| **Installed capacity of non-renewable power plant** | The total maximum capacity registered and capable of being generated by all non-renewable power plants (coal-fired power plants, gas-fired power plants, diesel-fired power plants) operating commercially in the province | MegaWatt (MW) | Directorate General of Electricity |
| **Installed capacity of renewable power plant** | The total maximum capacity registered and capable of being generated by all renewable power plants (hydroelectric power plants, wind power plants, biomass power plants, geothermal power plants, solar power plants, biogas power plants) operating commercially in the province | MegaWatt (MW) | Directorate General of Electricity |
| ***Output*** | | | |
| **PDRB** | Gross value added generated by all business units or economic sectors within a provincial area over a one-year period | Miliar Rupiah | BPS |

## RESULT AND DISCUSSION

**Table 3.** DEA Results

| DMU | Province | Efficiency Score | *Input Slack* | | *Peer Group* |
|---|---|---|---|---|---|
| | | | Installed capacity of renewable power plant | Installed capacity of non-renewable power plant | |
| **DMU1** | Aceh | 0,226 | 39,654 | 0,000 | 0 |
| **DMU2** | Sumut | 0,602 | 2422,797 | 0,000 | 0 |
| **DMU3** | Sumbar | 0,651 | 474,993 | 0,000 | 0 |
| **DMU4** | Riau | 0,616 | 907,734 | 0,000 | 0 |
| **DMU5** | Kepri | 0,338 | 0,972 | 0,000 | 0 |
| **DMU6** | Bengkulu | 0,297 | 308,518 | 0,000 | 0 |
| **DMU7** | Jambi | 0,553 | 64,099 | 0,000 | 0 |
| **DMU8** | Sumsel | 0,297 | 970,668 | 0,000 | 0 |
| **DMU9** | Babel | 0,253 | 114,808 | 0,000 | 0 |
| **DMU10** | Lampung | 0,726 | 488,524 | 0,000 | 0 |
| **DMU11** | Banten | 0,237 | 214,000 | 4626,000 | 0 |
| **DMU12** | DKI Jakarta | 1,000 | 0,000 | 0,000 | 31 |
| **DMU13** | Jabar | 0,767 | 3839,000 | 4872,000 | 0 |
| **DMU14** | Jateng | 0,494 | 486,000 | 7031,000 | 0 |
| **DMU15** | DIY | 1,000 | 0,000 | 0,000 | 27 |
| **DMU16** | Jatim | 0,861 | 499,000 | 4732,000 | 0 |
| **DMU17** | Bali | 0,301 | 2,431 | 0,000 | 0 |
| **DMU18** | Kalbar | 0,415 | 80,979 | 0,000 | 0 |
| **DMU19** | Kalteng | 0,297 | 395,721 | 0,000 | 0 |
| **DMU20** | Kalsel | 0,351 | 50,097 | 0,000 | 0 |
| **DMU21** | Kaltim | 0,663 | 125,584 | 0,000 | 0 |
| **DMU22** | Kaltara | 0,393 | 25,298 | 0,000 | 0 |
| **DMU23** | Sulut | 0,360 | 198,901 | 0,000 | 0 |
| **DMU24** | Gorontalo | 0,142 | 11,200 | 0,000 | 0 |
| **DMU25** | Sulteng | 0,102 | 828,000 | 820,000 | 0 |
| **DMU26** | Sulbar | 1,000 | 0,000 | 0,000 | 0 |
| **DMU27** | Sulsel | 0,554 | 990,939 | 0,000 | 0 |
| **DMU28** | Sultra | 0,491 | 0,000 | 0,000 | 0 |
| **DMU29** | NTB | 0,169 | 52,635 | 0,000 | 0 |
| **DMU30** | NTT | 0,242 | 45,467 | 0,000 | 0 |
| **DMU31** | Maluku | 0,511 | 0,000 | 0,000 | 0 |
| **DMU32** | Malut | 0,156 | 0,000 | 4436,125 | 0 |
| **DMU33** | Papua | 0,195 | 22,655 | 0,000 | 0 |
| **DMU34** | Pabar | 0,259 | 9,045 | 0,000 | 0 |
| **DMU35** | Papteng | 1,000 | 0,000 | 0,000 | 5 |
| **DMU36** | Papeg | 1,000 | 0,000 | 0,000 | 2 |
| **DMU37** | Papsel | 0,286 | 0,000 | 0,000 | 0 |
| **DMU38** | Pabarya | 0,149 | 0,000 | 0,000 | 0 |
| **Mean** | | 0,472 | 359,729 | 697,819 | |

The DEA scores have a mean of 0.472. The efficiency scores of the 38 units range from 0.102 to 1.000, and 5 of them are classified as efficient (efficiency score of 1). The efficient DMUs are DMU 12 (DKI Jakarta), DMU 15 (Special Region of Yogyakarta), DMU 26 (West Sulawesi), DMU 35 (Central Papua), and DMU 36 (Mountainous Papua). If the DEA score (lambda) is 1, the unit is considered efficient and thus does not need to use other units as a benchmark (Sihombing et al., 2024). Conversely, these efficient units can serve as benchmarks for inefficient units—those with DEA scores below 1, as indicated by the peer group results.

Efficient units will have no slack—that is, neither output variables added nor input variables reduced from a unit to be considered efficient—so the slack possessed by a unit indicates that the unit is inefficient. Therefore, slack will be zero if the unit has a DEA score of 1 (efficient). Consequently, DEA analysis will yield a benchmark standard to guide efforts to improve the allocation of input and output variables (slack) in inefficient units. In output-oriented analysis, for units with an efficiency score below 1 (inefficient), an increase in output variables is expected to be achieved without increasing input variables (Parwoto et al., 2021). Based on the results of the slack analysis on inputs, it was found that 26 provinces have slack, both in the installed capacity of renewable power plants and in the installed capacity of non-renewable power plants. However, slack in the installed capacity of non-renewable power plants tends to be higher, with an average value of 697,819 MW, while slack in the installed capacity of renewable power plants averages only 359,729 MW. This means that installed capacity for non-renewable power plants tends to be less efficient than installed capacity for renewable power plants.

Slack > 0 indicates excess input, which can be minimized because it causes inefficiency in the DMU and needs to be adjusted (Sihombing et al., 2024). The average slack results for both inputs indicate that without reducing the GRDP value as output, the average installed capacity of non-renewable power plants per province could be reduced by 697,819 MW, and the installed capacity of renewable power plants could be reduced by 359,729 MW. This indicates that non-renewable energy inputs are the primary source of existing inefficiencies. These results align with the study by Ul et al. (2024), which found that an increase in renewable energy consumption inputs improves DEA efficiency when GDP is used as the output variable.

Inefficiencies in non-renewable power generation are also highlighted by peer group analysis. The peer group identifies efficient units used as benchmarks against inefficient units so that the latter can become efficient (Sihombing et al., 2024). Of the 5 efficient provinces, 4 serve as benchmarks for other provinces: DKI Jakarta serves as a benchmark for 31 provinces, D.I. Yogyakarta for 27 provinces, Central Papua for 5 provinces, and Mountainous Papua for 2 provinces.

When compared to the total installed capacity of non-renewable power plants, these five provinces—excluding DKI Jakarta—do indeed have values below the national average of 2,271.84 MW, specifically: DKI Jakarta, Special Region of Yogyakarta, West Sulawesi, Central Papua, and Papua Mountains, at 5,396 MW, 7 MW, 2 MW, 717 MW, and 13 MW, respectively. This indicates a tendency for efficient DEA scores when the installed capacity of non-renewable power plants is at a low level. In the case of DKI Jakarta, although this province has an installed power generation capacity exceeding the national average, its DEA score—which is classified as efficient—indicates that the score is biased due to the presence of an outlier variable, namely its GRDP value.

The DEA technique can produce biased efficiency scores when the original data contains outlier variables (Mahmudah & Rohayana, 2018). The DKI Jakarta GRDP variable, as the output, is considered an outlier due to its extremely high value compared to the GRDP values of other provinces, a result of DKI Jakarta's economic conditions being vastly different from those of other provinces, given its role as both the administrative and economic center of Indonesia. Previously, research by G. F. Ramadhan & Sodik (2021) on per capita GRDP inequality across six Java provinces from 2016 –2021 also revealed high inequality values, with an average of 1.16 according to the Williamson index. This is attributed to differing concentrations of economic activity; specifically, DKI Jakarta achieved the highest per capita GRDP due to significant disparities in economic governance, human capital quality, science and technology, and regional development—factors that enable a region's productivity to improve and transform it into an economic hub. In fact, a study by Ode et al. (2024), which examined the issue of multicollinearity in regression analysis using 2020 provincial GRDP data in Indonesia as predictor variables, found that DKI Jakarta's GRDP data served as an outlier. Therefore, in this analysis, DKI Jakarta's efficiency score will be excluded. For the Special Region of Yogyakarta, this province serves as a benchmark for the other 27 provinces, underscoring its efficiency in utilizing power generation capacity inputs to produce GRDP output. The Special Region of Yogyakarta itself does indeed have more power generation capacity from renewable sources, totaling 8 MW, compared to non-renewable sources, which amount to only 7 MW. West Sulawesi also shows the same pattern, namely that efficient units tend to rely more on power generation capacity from renewable sources compared to non-renewable sources, with a difference of 13 MW (renewable) and 2 MW (non-renewable). The same finding was reported by Veronese et al. (2023), namely that regions relying more on renewable energy power generation have better DEA efficiency scores than those relying on non-renewable energy, with GDP as the output.

However, Central Papua and Papua Pegunungan showed different results, maintaining efficient scores despite having a smaller capacity of renewable power plants compared to non-renewable ones. This indicates that Central Papua and Papua Pegunungan have outlier variables, specifically their GRDP, similar to the previous case of DKI Jakarta. These two provinces achieved efficient DEA scores largely due to their low GRDP values, given their status as relatively new provinces, having been established as recently as 2022. A low GRDP value results in an efficient score because the small GRDP is considered commensurate with the inputs provided.

## CONCLUSION

The slack in the installed capacity of non-renewable power plants tends to be higher (697,819 MW) than that of renewable power plants (359,729 MW), which means that the installed capacity of non-renewable power plants tends to be less efficient. There are 5 provinces classified as efficient, but 3 provinces are considered outliers; thus, the truly efficient provinces are Yogyakarta Special Region and West Sulawesi, with a DEA efficiency score of 1. Efficient provinces tend to have a larger installed capacity from renewable power plants than from non-renewable ones. Therefore, it is recommended that stakeholders intensify the use of renewable energy as the primary source of electricity generation to achieve more efficient economic growth and address regional GDP disparities.

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