International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 8; August 2025
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Application of Data Envelopment Analysis to the Evaluation of the Nigerian Electricity Company

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DOI: https://doi.org/10.52403/ijrr.20250810

ABSTRACT

Electricity distribution is vital for Nigeria's economic growth, but it faces operational challenges. This study evaluates the performance of Nigerian electricity distribution companies from 2015 to 2022 using DEA models (CCR and BCC), Super-efficiency DEA, and the Malmquist Productivity Index (MPI) to assess efficiency and productivity changes. A two-phase DEA model incorporates environmental factors like regulations and economic conditions. The findings highlight Ikeja (IKEDC) and Eko (EKEDC) as top performers, while Enugu (EEDC) and Jos (JEDC) show declining productivity, requiring improvement measures. Benin (BEDC) and Kaduna (KEDC) demonstrate potential scale efficiencies under the BCC model. Some companies have improved efficiency, while others struggle due to mismanagement and outdated technology. Policy reforms, smart metering, and infrastructure investments are crucial for improving operational efficiency. Performance benchmarking and regular monitoring can help address inefficiencies. This research provides valuable insights for decision-makers and stakeholders aiming to enhance Nigeria's electricity distribution sector.

Keywords: Efficiency Analysis, Data Envelopment Analysis (DEA), Electricity Distribution Companies, Nigerian Power Sector, Operational Efficiency

1. INTRODUCTION

Regarding both utility companies and decision-makers, the effective discharge of electricity is crucial. Electro-dispersence efficiency involves managing the necessary tools for transmitting power, in addition to considering cost implications. Efficiency calculations provide insights into how well a particular distribution company has performed compared to its peers and therefore identify weaknesses, resulting in reduced costs, minimized energy waste, and improved service delivery.

The process of distributing electric energy involves delivering generated power to end consumers. Distribution companies maintain the grid that supplies power, serving as the link between customers and the electric wires connecting homes, buildings, and industries. As the demand for electricity rises, enhancing the efficiency of the distribution system becomes essential to ensure that supply keeps pace with this increasing demand, thus preventing unnecessary cost escalations. Additionally, it requires analyzing efficiency to develop policies like tariffs and other charges, which ultimately lead to fair pricing systems and contribute to maintaining equilibrium in energy systems overall.

Electricity distribution efficiency in developing countries such as Nigeria has much further implications for economic development, industrial growth, and social welfare. An inefficient distribution network generates frequent power outages, very high technical and commercial losses, and unsatisfied consumers. These problems are a heavy load on an already overloaded power sector and hinder national development ambitions.

2. REVIEW OF LITERATURE

Inefficiency evaluations within the electricity industry, such as data envelopment analysis (DEA), have been widely utilized, especially in underdeveloped countries with many distribution inefficiencies. This method has no set parameter; hence, it provides a non-parametric way to evaluate how DMUs perform compared to their business counterparts. This approach considers several input factors (such as the number of customers or energy consumption) and output factors like revenue collected or energy distributed, thus forming an excellent basis for classifying DMUs as efficient or inefficient.

There has been a global surge in the use of Data Envelopment Analysis (DEA) in the performance evaluation of electricity distribution firms, especially in developing countries with challenges in their operations. According to Charles, Cooper, and Rhodes (1978), DEA is a non-parametric model that measures the efficiency of decision-making units (DMU, n.d.) by considering several input and output variables. This is especially true when evaluating public utilities' performance, where many variables come into play.

Omrani et al. (2020) utilized the Data Envelopment Analysis (DEA) technique to measure Brazil's electricity distribution companies' performance. Their assessment results indicated that regulatory frameworks also influence the behavior of dominant and efficient firms in addition to their operational efficiency. This was because such firms concentrated their efforts on areas with many customers and low-priced services. The results echoed the concerns regarding the need for policy changes and investments in physical facilities to improve operations, which are also dynamics applicable in Nigeria.

In India, Kumar and Garg (2018) carried out a DEA evaluation of state-level distribution companies. They concluded that management-led companies with advanced metering infrastructure were comparatively more efficient. They contended that technological innovations, such as smart meters, are essential in reducing technical and commercial losses, which is also the case in Nigerian companies.

In a study by Khosravia et. al, for their cohort, published in (2015), the Malmquist Productivity Index was used to show, over time, changes in productivity among electricity companies in China. It turned out that rather than improving efficiency, the development of technology drove productivity the most. The study highlighted the necessity of constantly upgrading technology to sustain operational performance, something very important to Nigerian firms.

Karekezi and Kimani (2002) noted, in their assessment of the energy sector in Kenya, similar inefficiencies were identified in Nigeria, including electricity theft and non-payments. The authors suggested targeted policy reforms and improved resource allocation, which are similar to the suggestions made in this study.

While some studies have considered the Nigerian electricity sector until very recently, most of them dealt with generation rather than distribution. For instance, Oyedepo et. al (2014) used the DEA methodology to examine generation efficiency in Nigeria without disregarding the infrastructure and management issues. However, very little has been done regarding the performance assessment of the distribution companies over the years.

In this regard, this study provides the gap that exists in the literature on the performance of Nigerian electricity distribution companies in terms of their operational efficiency and productivity changes between 2015 and 2022 by employing the CCR and BCC DEA models alongside the Malmquist Productivity Index. The research also uses a second-stage DEA model to analyze the effect of external variables like the regulatory environment and the nation's economy on efficiency. This strategy has been explored less in Nigeria's distribution sector. By emphasizing annual efficiency trends and environmental factors that change over time, this study provides new findings that could help in the future restructuring of the Nigerian power sector.

2.1 DEA in Electricity Distribution:

Many investigations utilized DEA to assess the efficacy of power distribution firms globally, more so in developing countries characterized by severe resource limitations and poor operational processes. In Brazil, de Souza et al. (2014) studied the performance of electric distribution firms using DEA and how rules affected it. In particular, they pointed out that external factors like regulation and economic situation are critical in determining operational efficiency. Next, in India, Kumar and Garg (2018) conducted a DEA study to evaluate the performance of state-based electricity stewards. The study also showed that to be efficient enough in this work, one must invest heavily in infrastructure and metering technologies. In China, the DEA studies the performance of provincial electricity companies and identifies technological upgrades that would improve efficiency and reduce energy losses Gu et. al, (2014).

2.2 DEA Applications in Nigeria:

Despite the widespread use of DEA in electricity distribution studies, limited research has focused on Nigeria. However, a few notable studies exist. In 2005, Roy et. al, (2023) analyzed the Nigerian electricity sector's performance and highlighted inefficiencies resulting from gaps in infrastructure and mismanagement practices. Nonetheless, the present study has not been modeled using DEA. Oyedepo et. al (2014) evaluated Nigeria's power generation inefficiency by applying the DEA methodology, although distribution companies were not considered. The deficiency in suitably examining DEA in Nigeria's power distribution companies is underreported in the literature, making this research novel and significant for evaluating the efficiency of Nigeria's power distribution industry (2015-2022) using DEA models. This research project provides a comprehensive framework for assessing and enhancing the performance of electricity distribution companies in Nigeria, focusing primarily on these firms through the application of both standard DEA models and advanced strategies such as super-efficiency data envelopment analysis (DEA) and the Malmquist productivity index.

2.3 Research Gap and Novelty of the Study

Electricity distribution companies in Nigeria face many challenges, including the inability to deliver energy with few losses efficiently. This is made worse by rehabilitating old technologies, revenue collection problems, and geographical differences in operations. Studies have shown that most attention has been on the generation side of the power sector, or there have been short periods of analysis, and there is not enough literature on the distribution companies in Nigeria even though they rank high in their importance in the energy value chain (Oyedepo et. al, 2014). In the electricity sector, it is also uncommon in Nigeria to find studies that have used Data Envelopment Analysis (DEA) and, even rarer, studies that consider contextual features such as regulatory or market conditions that are critical for performance.

The current study fills these voids by evaluating distribution companies' efficiency for seven years (2015–2022) as in the year above. The originality of this work is not only in integrating the CCR and BCC DEA models for the measurement of efficiency at constant and variable scale efficiencies but also in including the application of super-efficiency DEA to ascertain rankings among the efficient DMUs. In addition, this research uses the Malmquist Productivity Index (MPI) to measure productivity change over the years and a two-stage DEA to assess the impact of external factors (e.g., tariffs and regulation changes) on efficiency. This helps in understanding the operational problems concerning the possible strategies it could adopt, which is helpful to policymakers and the industry.

This research is unique because it applies DEA to Nigerian electricity distribution firms for an extended duration (2015-2022), allowing for a detailed evaluation of efficiency patterns over time. Additionally, incorporating super-efficiency DEA to grade efficient DMUs and the Malmquist Productivity Index to quantify productivity changes introduces advanced DEA methods rarely utilized in Nigeria. Furthermore, this study provides a comprehensive environmental analysis through a two-stage DEA approach that indicates how external factors, such as regulatory shifts and economic variables, shape efficiency.

In conclusion, this research fills an essential void in the existing literature by undertaking an extensive analysis of the efficiencies of Nigeria's electricity distribution firms. The results generated from the study will be significant tools for policymakers and distributive companies trying to improve their operational efficiencies, minimize energy wastage, and maintain economic viability in tough times.

3. METHODOLOGY

3.1. Simplified Explanation of DEA Models (CCR and BCC)

Data Envelopment Analysis (DEA) is an extensively applied technique for gauging the comparative effectiveness of decision-making units (DMUs) by utilizing diverse inputs to generate various outputs. Within the boundaries of Nigerian power distribution firms, DEA helps us evaluate how effectively distinct corporations change their resources (inputs) into services (outputs). Two commonly known models under DEA are- the CCR (Charnes, Cooper, and Rhodes) model and the BCC (Banker, Charnes, and Cooper) model; they differ in their assumptions concerning returns to scale decisions.

3.2. CCR Model (Constant Returns to Scale)

The CCR model postulates that all DMUs have constant returns to scale (CRS). Thus, increasing input by some multiples will increase output by the exact multiples. To put it differently, regardless of the size of operations within a firm, its efficiency will be perceived as constant. Where the size of the DMU does not influence efficiency, applying the CCR model is justified.

If a distribution company doubles its inputs, such as employing more people or providing better facilities, we assume that the outputs, for instance, energy delivered or revenue collected, will also double. The computation of the efficiency score in the CCR model is based on the ratio between weighted outputs and weighted inputs; thus, receiving a score of 1 (or 100%) implies a high level of efficiency compared to peers.

Mathematically, the CCR model solves the following linear program:

$$\text{Maximize: } \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}$$

Subject to,

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad \forall j = 1,2,\dots,n$$

$$u_r \geq 0 \quad \forall r \quad \text{and} \quad v_i \geq 0 \quad \forall\, i$$

Where:

- y_{rj} represents the r-th output for DMU j
- x_{ij} represents the i-th input for DMU j
- u_r and v_i are the weights assigned to the outputs and inputs, respectively

3.3. BCC Model (Variable Returns to Scale)

The BCC model is based on variable returns to scale (VRS), meaning a firm's efficiency can differ according to size. This model allows for the possibility that smaller or larger companies may be more or less efficient. The flexibility provided means that returns to scale can increase or decrease. For example, a small distribution company may manage its operations better and more efficiently due to closer location management, or a large firm may leverage its size to operate more advantageously. In cases where DMUs operate under different conditions, including regulatory environments or market sizes, the BCC model is more applicable. The BCC model improves upon the CCR model by introducing a variable incorporating operational scale. While the mathematical form is similar, it includes a convexity constraint to capture variable returns to scale. Mathematically, the BCC model can be written as:

$$\text{Maximize: } \frac{\sum_{r=1}^{s} u_r y_{rj} + u_0}{\sum_{i=1}^{m} v_i x_{ij}}$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r y_{rj} + u_0}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad \forall j = 1,2,\dots,n$$

$$u_r \geq 0 \quad \forall r \quad \text{and} \quad v_i \geq 0 \quad \forall\, i$$

Where u_0 is a free variable that adjusts for the scale of operations, allowing the model to capture varying returns to scale.

3.4 Illustrative Example

Imagine two distribution companies, Company A and Company B:

- Company A has 100 employees, manages 500 kilometers of power lines, and delivers 1000 MWh of electricity.
- Company B has 200 employees, manages 1000 kilometers of power lines, and delivers 2100 MWh of electricity.

In a CCR model, the analysis would assume that if Company A doubled its inputs (employees and kilometers of power lines), it should deliver twice the output (2000 MWh). However, in the BCC model, Company B might benefit from economies of scale, delivering more than twice the output for the same input increase.

3.5 Description of the Data Collected

The study uses input and output data from Nigerian electricity distribution companies between 2015 and 2022. The data is obtained from regulatory reports, company financial statements, and performance metrics published by the Nigerian Electricity Regulatory Commission (NERC). The inputs and outputs used in the DEA models are tabulated in Table 1:

Variable	Description	Unit	Source
Total number of customers	Total number of electricity consumers served	Count	NERC reports
Number of metered customers	Consumers with functioning electricity meters	Count	NERC reports
Number of estimated customers	Consumers are billed based on estimated consumption	Count	NERC reports
Tariffs	Average electricity tariff per kWh	Naira/kWh	Company financial statements
Revenue collected	Total revenue generated from electricity sales	Naira	Company financial statements
Energy billed	Total amount of energy billed to customers	MWh	NERC reports

Table 1: Summary of Inputs and Outputs

This period can best be described as extended operational and financial turmoil that has adversely affected the electricity distribution industry in Nigeria. The poor performance of the distribution networks, in addition to poor infrastructure and poor revenue collection, has made them persistently ineffective, leading to more energy losses and curtailed service delivery. However, the issues presented in this period are of such a structural nature that there is a need to conduct extensive studies to look at what the lines appear to do and whether any efficiency improvements have been visible over the years.

3.6 Assumptions Underlying DEA Models

Key assumptions had to be made to interpret and reliably interpret the results of this study, which employed data envelopment analysis (DEA) models. Knowing these assumptions is important for accurately assessing Nigerian electricity distribution firms' efficiency. The two DEA models used in this research, CCR (constant returns to scale) and BCC (variable returns to scale), rely on specific assumptions for the analysis.

3.6.1. Assumption of Multiple Inputs and Outputs

The DEA presumption is that each electricity distribution company's decision-making units (DMUs) generate numerous results with several raw materials in this scenario. Through input-output conversion between DMUs, DEA models analyze their efficiency in various dimensions, such as tariffs or the number of customers considered as inputs and revenue collected or energy charged as outputs. The inputs and outputs are assumed to be non-negative, meaning that each DMU must produce positive quantities of outputs and use positive quantities of inputs.

3.6.2. Assumption of Homogeneous DMUs

DEA assumes that the DMUs being analyzed are comparable and operate under similar conditions. In the context of this study, the electricity distribution companies are all assumed to provide the same basic services (electricity distribution) using comparable resources (inputs) to achieve comparable goals (outputs). While these companies may differ in size, location, or customer base, DEA assumes that they operate within the same industry and follow similar operational objectives.

3.6.3. Assumption of Constant or Variable Returns to Scale

The CCR model assumes constant returns to scale (CRS), meaning that if a DMU increases its inputs by a certain factor, its outputs will increase by the same factor. This assumption implies that the size of the operation does not impact the DMU's efficiency. For example, doubling the number of employees and the length of the distribution network is expected to double the amount of energy billed and revenue collected. The BCC model tackles the assumption by allowing for variable returns to scale (VRS). It follows that inputs and outputs may differ in their relationship depending on the size of operations. Small or big DMUs can enjoy economies of scale (where bigger is better) or diseconomies of scale (where smaller is better).

3.7. Convexity Assumption (BCC Model)

The BCC model carries an added convexity constraint to evaluate efficiency on a convex combination of DMUs. This assumption allows the model to account for variable returns to scale, where small or big DMUs may not be as efficient as average-sized ones. The convexity hypothesis reflects that an assemblage of various DMUs could be a benchmark for efficiency assessment.

3.8 Assumption of Perfect Knowledge

DEA assumes that accurate data for inputs and outputs are present in complete form. The inputs (e.g., no of clients served; tariff rates) and outputs (e.g., total sales made by the firm) used in the model are assumed to be free of measurement errors. This assumption is crucial because if there are mistakes in the information used, it may cause wrong efficiency assessments. Furthermore, the DEA assumes that there is knowledge regarding relationships between inputs and outputs and that no unobservable factors affect the efficiency outcomes.

3.9. Assumption of No Random Error

A shortcoming of DEA is the belief that all deviations from the efficient frontier come from inefficiency, whereas random errors and other outside vectors could also be responsible for such deviations. This means that any deviations in performance are interpreted as inefficiencies of the DMU rather than random errors, which could arise from measurement inaccuracies or external shocks (e.g., natural disasters, unexpected policy changes).

3.10. Assumption of No Functional Form
Unlike parametric methods, DEA does not assume a specific functional form (such as a linear or quadratic relationship) between inputs and outputs. Instead, DEA constructs an empirical efficiency frontier based on the observed data without imposing assumptions about the underlying production function. This makes DEA a flexible tool for efficiency analysis, especially when the exact relationship between inputs and outputs is unknown.

3.11. Assumption of Input or Output Orientation
DEA models can be either input-oriented or output-oriented. In input-oriented DEA models, the focus is on minimizing the inputs required to produce a given output level. This assumption is appropriate when a DMU's main objective is to reduce resource usage while maintaining the same output levels. In output-oriented DEA models, the focus is on maximizing the outputs produced from a given set of inputs. This assumption is appropriate when the goal is to increase output levels without changing the inputs.
In this study, the choice between input-oriented or output-oriented models is made based on the specific objectives of the electricity distribution companies. On the other hand, an input-oriented approach would be more suitable if the aim is to reduce the inputs (like the number of workforce or distance in kilometres of distribution lines), yet keep the same amount of electric power supplied.

3.12. Assumptions Specific to the Study's Context
Besides the DEA's common presumptions, Nigerian electric power distribution companies have additional specific assumptions:

3.12.1. Regulatory Consistency:
It is presumed that corporation's function in similar regulatory environments, with the Nigerian Electricity Regulatory Commission (NERC) offering common directives for the entire sector. Despite potential local variations, this presumption enables the comparison of the DMUs.

3.12.2. Market Stability:
According to assumptions, the electric supply field will remain constant throughout the research period (2015-2022). However, despite policy alterations or economic factors being considered, no predictions have been made that suggest major changes in the way businesses operate.

3.12.3. Comparable Tariff Structures:
Despite companies varying in their tariffs, it is presumed that these discrepancies in tariffs mirror common economic realities and can be matched with each other based on regions. Therefore, tariffs can be regarded as an acceptable ingredient of the DEA approach.
The assumptions in this study serve as a basis for using DEA models to investigate electricity distribution firms in Nigeria. By indicating the assumptions, it is assumed that the results are based on a real and coherent context, such that meaningful efficiency comparisons can be made among companies and across time. This also aids in interpreting results, identifying areas that need more research or improvement, and understanding DEA limitations.

4. RESULTS AND DISCUSSION
Findings from this research furnish essential knowledge regarding how effective Nigerian power supply companies were between 2015 and 2022. Employing DEA models (CCR and BCC), the efficiency scores indicate an all-inclusive method of assessing the extent to which these corporations utilize their available resources for production purposes. Furthermore, analysis of the efficiency scores over different years and models affords a better perspective of what improvements could be made in the industry and obstacles that need to be addressed.

4.1. Interpretation of Efficiency Scores

Efficiency scores obtained from DEA are relative measures of the performance of each distribution company compared to the best-performing distribution companies in the sample (DMUs). Within the CCR model, a score of 1 (i.e.100%) indicates that a company is efficient and lies on the efficiency frontier, implying it utilizes its inputs (customers or tariffs) in an optimal way to produce maximum outputs (energy billed, revenue collected). Companies scoring below 1 are deemed inefficient, as they could either reduce their inputs or increase their outputs to achieve higher efficiency.

Ikeja (IKEDC) and Eko (EKEDC) always score 1 in the CCR model, which shows that they have performed optimally and efficiently throughout the years. Other DMUs can use these firms as a standard, showing how healthy resources should be managed. Enugu (EEDC) and Jos (JEDC), on the other hand, show declining efficiency over time, particularly from 2017 onwards, with scores dropping significantly below 1. Such observers observe persistent time wasters in utilizing your sources for various reasons, like work problems, poor management methods, or the lack of them altogether.

In the context of variable returns to scale according to the BCC framework, firms like Benin (BEDC) and Kaduna (KEDC) seem more efficient than when assessed with the CCR model. This indicates that although they may not be operating at optimum levels in terms of their size, their performance is commendable based on this criterion. This implies that they (the companies) can improve efficiency if they adjust their scale.

The continuously outstanding performance of Ikeja (IKEDC) and Eko (EKEDC) in CCR and BCC models reinforces their status as the country's best electricity distribution companies. Their ability to sustain high efficiency regardless of size is a manifestation of good management and operational practices.

The conclusions of this study support previous studies on the application of DEA in the electricity industry, especially in developing nations characterized by distribution inefficiencies. For instance, de Souza et. al, (2014) and Kumar and Garg (2018) applied DEA to electricity distribution in Brazil and India, respectively, and found similar trends: Some firms were always better than others, while some could not cope with inefficiencies. Both investigations highlighted the influence of external variables like infrastructure outlays and policy frameworks regulating the sector as catalysts for enhancing efficiency.

Very few studies have specifically applied Data Envelopment Analysis (DEA) to distribution companies in Nigeria. However, some studies within the broader power sector of Nigeria, like Oyedepo et. al, (2014), have drawn attention to infrastructure deficits, poor management practices, and regulatory inconsistencies as key causes of inefficiencies. Our study extends this work by looking at the distribution companies specifically, giving an empirical account of their efficiency profiles over time. Using both CCR and BCC models alongside super-efficient DEA and Malmquist Productivity Index represents not only an original input into the literature but also fills a gap that has been neglected in studies concerning electricity distribution in Nigeria.

4.2. Practical Implications for Policymakers and Industry Stakeholders

The outcomes of this research bear several significant implications for policymakers, regulators, and industry stakeholders seeking to enhance the efficiency of electricity distribution companies in Nigeria.

4.2.1. Targeted Interventions for Inefficient DMUs

Targeted interventions should focus on companies like Enugu (EEDC) and Jos (JEDC), which exhibit consistently low efficiency scores. Updating distribution networks and metering systems may decrease technical losses and enhance efficiency. Enhanced managerial practices and appropriate resource allocation must be embraced to mitigate the inefficiencies. A performance improvement path could be indicated by benchmarking well-performing firms' performance against Ikeja's (IKEDC) performance.

4.2.2. Encouraging Scale Adjustments

The analysis shows that some distribution companies do not operate to their potential in certain contexts, which accounts for the differences in the results produced by the CCR and BCC models. In particular, the Benin Electricity Distribution Company (BEDC) and the Kaduna Electricity Distribution Company (KEDC) perform better when operating at a scale that is less than their present scale. Hence, there is a call for the relevant authorities to look into the possibility of mergers, regional integration, or renegotiating operating areas so that these distribution companies can operate and, therefore, be more efficient. For example, the Nigerian Electricity Regulatory Commission (NERC), a regulatory authority, can create policy measures to enhance scale efficiency. One such policy could encourage the provision of financial resources in industries where scale efficiency is possible for maximal results.

4.2.3. Regulatory Reforms

According to the study, regulatory inconsistencies and tariff systems contribute to sector inefficiencies. For instance, firms situated in areas with low tariffs might not be able to raise enough income, resulting in operational inefficiencies. Cost-reflective tariffs should be implemented to maintain the financial viability of distribution firms and keep them affordable to consumers. Establishing prices that mirror the actual cost of electricity provision would equip the companies with cash for developing their infrastructure and enhancing service delivery. If there are ordinary rules in all regions, ineffectiveness due to disparity among areas may be reduced. Streamlining processes can also help cut down on distribution companies' running expenses.

4.2.4. Technological Upgrades

According to the data available until October 2023, Ikeja Electric Distribution Company (IKEDC) and Eko Electric Distribution Company (EKEDC) have consistently recorded high-performance levels. This indicates that they have invested heavily in their metering systems and distribution infrastructures, which increases efficiency. Encouraging the adoption of smart grid technologies, such as real-time monitoring and automated fault detection, could significantly enhance the operational efficiency of other distribution companies. These technologies would reduce technical losses, improve billing accuracy, and enhance customer satisfaction.

4.2.5. How These Results Can Be Used to Improve Efficiency

The insights gained from this study can be directly applied to improve the efficiency of Nigerian electricity distribution companies in several ways. Low-performing companies can use high-performing peers, such as Ikeja (IKEDC) and Eko (EKEDC), as benchmarks for best practices. By studying their operational models, management practices, and technological investments, other companies can identify areas for improvement. NERC could facilitate this benchmarking approach by creating forums for sharing industry best practices.

Companies with low-efficiency scores, particularly under the CCR model, need to optimize their resource use. This could involve improving billing and revenue collection by investing in metering infrastructure and reducing energy losses through better grid maintenance and technological upgrades.

Next, encouraging regional collaboration or mergers between distribution companies could address issues of scale inefficiency. Companies operating at a suboptimal scale could benefit from increased resources, shared infrastructure, and enhanced bargaining power in procurement and operations.

Finally, policymakers and industry stakeholders should implement continuous monitoring systems that use DEA to assess distribution companies' performance regularly. Detecting system errors may assist in obtaining precision in interventions over time and following the results of reforms already made.

Using DEA models, this study has provided an in-depth assessment of the effectiveness of Nigerian electricity distribution firms' operations. In terms of performance, there are wide variations among almost all companies, with some being consistently efficient while others experience inefficiencies in terms of operation or size. This has made it necessary for policies to be targeted at rectifying them while encouraging the adoption of technology and new regulations to improve power system performance across the board. Applying the findings would help various players in the industry move towards a more dependable and efficient electric power distribution system, which is crucial for Nigeria's economic growth and development.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

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How to cite this article: Sabo, Nelson Pandi. Application of data envelopment analysis to the evaluation of the Nigerian electricity company. *International Journal of Research and Review*. 2025; 12(8): 78-87. DOI: *https://doi.org/10.52403/ijrr.20250810*

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